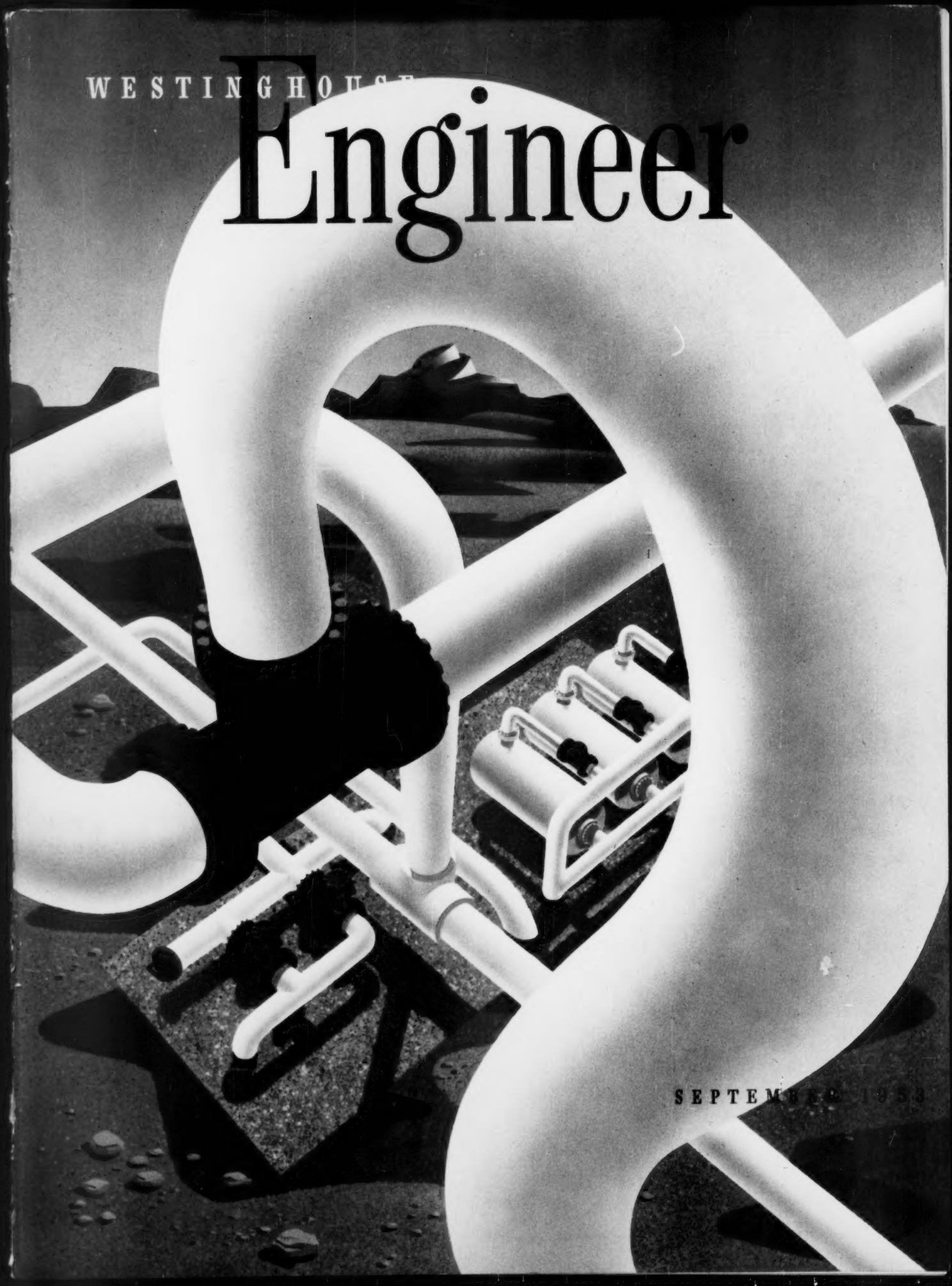
WESTINGHOUSE

Engineer



SEPTEMBER 1953

AN ENGINEERING BYWORD

IMPROVEMENT

A cartoonist recently portrayed two unhappy cavemen, surrounded by their most modern equipment—a primitive stone-wheeled cart, and simple eating utensils—and remarking sadly that all the really important inventions had already been made. There was nothing worthwhile left to invent. These gentlemen were obviously not the counterparts of today's engineers. For the remarkable thing about engineers is that, despite the technical excellence of today's devices and machines, a note of pessimism almost never is heard. The fact is that in no field of technical endeavor is progress at a standstill. The degree of advance may vary widely; but whether the field is old or new, the progress in small increments or giant strides, the engineer, with his usual ingenuity and thoroughness, never reaches a complete impasse. There are always ways to improve present devices, new machines and systems to develop, new ways to use the old, or new and untried fields to explore. The need for more and better engineering is always evident, and the engineer's response is usually prompt. Examples of this are everywhere in any technical field. Consider a few from the electrical industry.

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Direct-current electric welding dates back many decades. Actually a d-c welding machine is a relatively simple device, consisting of an m-g set to provide the welding current, and an adjustable control for regulating the current. In 1949, Westinghouse engineers introduced a new concept in d-c welders—a machine utilizing selenium rectifiers to provide direct current, thus eliminating the need for m-g sets as a power supply. This, in effect, combined the desirable characteristics of d-c welding with the advantages of using a-c power. Despite this rather sizable improvement, however, welding engineers embarked on a new development program almost immediately. The result—a new d-c rectifier welder featuring interchangeability of parts with the a-c welder, and an aluminum-wound three-phase transformer and reactor. Another innovation consists of winding both transformer and reactor on the same core. The net result is approximately 25 percent reduction in the weight of the machine, and about 15 percent reduction in height. Also this has the benefit of saving copper.

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Substituting an electrical device for a complex or bulky mechanical system is often a highly desirable engineering accomplishment. Take for example the recent substitution of a Synchrotie system for the complex assortment of shafts and bevel gears used to control the horizontal adjustment of the vertical rolls in a universal rolling mill. These rolls, one on either side of the run-out table, maintain the desired width and hold a square edge on the material being rolled. In adjusting these rolls, care must be taken to hold them equidistant from the vertical center of the mill. This adjustment is now held by a Synchrotie used in conjunction with the two d-c motors that move the rolls in and out. An electrical device and a few wires thus eliminate the heavy shafts and bevel gears.

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A seemingly simple new wrinkle often produces valuable results. Almost literally that is the case with an improvement to the Hipersil cores for specialty and electronic transformers. The strip for these cores is now slightly corrugated before being wound. The resultant core is more closely integrated and thus mechanically stronger, which means more perfect sections when the core is cut apart for assembling with the windings, and during transformer operations. Simple, but ingenious.

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Perhaps the most unusual "new" developments involve the reappearance of an old device in modern form. Frequently an engineering idea is born, but does not attain its full growth immediately—perhaps because the need for the device has not yet appeared, or because it cannot be developed properly with the knowledge at hand. The most striking recent case involves the magnetic amplifier. Saturable reactors are by no means new devices, but it was not until World War II that their full benefits began to be realized. The Germans seized upon magnetic amplifiers as a means of reducing maintenance aboard their naval vessels; they were static devices, and required essentially no man-hours or specially trained personnel for repair or upkeep. After the war, developments in magnetic materials suddenly boomed the magnetic amplifier into prominence. It has since been applied to a wide range of industrial controls, proving especially suitable for those applications where reliability and low maintenance are prime factors. To name a few, it has already been applied to such widely different applications as aircraft control systems, an excitation system for large generators, a log-carriage drive, a steel-mill speed regulator, a textile slasher drive, a paper-machine control, and many others—each requiring engineering design. And the full possibilities of the "new" device for control or regulation have yet to be explored!

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Simplification of a design or a system is always a desired engineering improvement, and is an ever-present challenge. A typical example is a consolidation of control elements for a d-c power-supply system for aircraft. As aircraft electrical systems have grown, the number of control components has kept pace. Usually the electrical designer has added each new device to the plane wherever he could find a place for it, which meant a lot of looking and considerable wiring. Now the several control elements are arranged together in one plug-in chassis. A later refinement further simplified this control panel. A new single-piece base, die-cast of aluminum, takes the place of 50 pieces that previously had to be assembled into one; and a molded plastic support for the components replaces 140 separate pieces.

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And every so often comes a startling new scientific discovery that opens up broad areas of development possibilities for the engineer. Such is apparent in the advent of nuclear energy for peaceful purposes. Within the broad range of engineering problems involved in designing a practical nuclear-reactor power system lie enough variety to tax even the most inventive engineer. But even without such spectacular and obvious problems as those involved in harnessing the atom, the engineer will never run out of important possibilities.

The very choice of engineering as a profession implies—among other things—a curious and inventive mind. The day will never come when the engineer—like the unhappy caveman—throws up his hands and says, "There's nothing more to do; all the important developments have been made."

R.W.D.

WESTINGHOUSE Engineer

VOLUME THIRTEEN SEPTEMBER, 1953 NUMBER FIVE

On the Side

The Cover—The eye-catching thing about a pipeline pumping station is the neatness and cleanliness—and sometimes even the scenic beauty—of its appearance. The array of gleaming white pipes, with their contrasting colored valves and connections, has become almost a symbol of the pipeline industry. It is this part of the pipeline operation that cover artist Dick Marsh has chosen to represent the industry, with an artistic arrangement of white pipes against a background of blue skies and brown earth.

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Growth of Westinghouse development work in the guided missile field has necessitated expansion of the engineering facilities of the Electronics Division. A new engineering subdivision will concern itself exclusively with development, design, and manufacture of equipment for high-speed, high-altitude missiles.

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Eastern Venezuelan oil fields of the Mene Grande Oil Company will use three 5000-hp gas turbines to supply electric power for oil- and gas-pumping stations. Burning natural gas, a waste product, the turbines will form a central station and replace present scattered gas-engine-driven power plants. Gas turbines are not only much lighter and smaller than steam turbines of the same capacity, but use only a fraction of the cooling water. Each unit will be made up of an axial-flow compressor that handles 400 000 pounds of air per hour, a combustion system to mix and ignite fuel and compressed air, and a five-stage turbine.

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PIPELINES

Great Underground Highway

One seventh of the ton-miles of freight transported in the United States is by a system that is both invisible and silent. Its lines total more than a half million miles, equal to 200 times the coast-to-coast distance and roughly twice as much as the total railroad mileage. And it is continuing to grow. This is the pipeline system for moving crude oil, petroleum products, and natural gas.

CONSIDER the pipeline business! To lay a pipeline a thousand miles from an oil or gas field across plain and mountains to a consuming area obviously takes a bit of doing—and a great deal of money. But after that, look! It should be a simple matter to pump oil or gas in at the field end, give it an additional push at widely spaced intervals—and let the fuel flow out at the receiving end. Pipeline companies have no empty vehicles to return; no cars to build or service. The product presents no problem of size or shape, or of packaging; delivery is continuous, and predictable with exactitude. The system wastes no power carrying itself around. The line is below ground, out of sight; it makes no noise, and is beyond the reach of storms. Theft is extremely difficult. It occupies almost no usable land, and causes no traffic accidents. Relatively little manpower is required; at operating stations equipped with automatic controls the crew members serve more as observers than as operators.

Pipeline operation appears to be a cinch. Until it is looked at more closely, that is. Or until one has talked with an experienced pipeliner. A pipeline system is admittedly free of many of the problems besetting transport systems functioning on rails, waterways, macadam, or in the air. Instead, the underground pipeline system possesses its own special brand of difficulties.

Foremost, the product handled always presents the risk of leaks. This calls for the best of engineering planning and eternal vigilance at every tank, pump, and valve. The pipe, although buried beyond weather's reach, has many enemies. Every inch of pipe is subject to chemical corrosion both inside and out, and to electrolysis. Every subterranean crossing of a major river is a heavy investment and is always subject to damage from floods and whims of the stream. A line well anchored below river bottom one year may lie exposed in a dry bed the next, the river at the spring flood having decided to move its channel, perhaps taking the unprotected approaching line with it. Many a length of pipe has been the victim of a ditching machine or earth mover working on some unrelated project, since the shallow covering soil, a layer only two or three feet deep, soon shows no marks of the pipe's existence. Surges, an old story to electrical engineers, also cause pipeliner's headaches. The closing of a liquid-line valve in Illinois is felt in Texas about a half hour later. And if some combinations of valves are operated simultaneously or in a critical timing or sequence, resonant surges are established that may cause damage or false operation of pressure-sensitive controls. A line is always subject to the possibility of premature obsolescence resulting from development of new production closer to market. So, we find, pipelining is a field of its own, with its own advantages, its own problems.

The Industry

The pipeline industry is characterized by high capital costs and low operating expenses. The total investment in the prop-

Written by Charles A. Scarlott based on information provided by the American Petroleum Institute, American Gas Association, General Petroleum Corporation, Tennessee Gas Transmission Company, Humble Pipe Line Company, Standard Oil Company, Gulf Oil Corporation, Shell Oil Company, Socony-Vacuum Oil Company, Great Lakes Pipe Line Company, Sun Oil Company, Cities Service Company, Plantation Pipe Line Company and Westinghouse.

erty of oil pipeline carriers reporting to the Interstate Commerce Commission in 1950 was 1.66 billion dollars. About 70 percent of the investment is for pipe and in laying it. Unlike other forms of transport, pipeline terminal facilities cost little. Also the operating labor costs are relatively small. The persons employed by pipeline companies of common-carrier status in the United States in 1950 were only 26 000. Corresponding figures for railroads were 1 300 000; intercity trucks, 440 000; and waterways, 82 000.

Pipelines divide into three categories: two for liquids, one for gas. One type of liquid line handles a single substance, crude oil, i.e., petroleum almost as it comes from the ground. There are, however, scores of different grades of crude oil. The second class of liquid line handles many refinery products—gasoline, kerosene, diesel fuel, heating oil, etc.—often several different batches at one time. Gas lines move but a single product, natural gas, which is comparatively uniform as to Btu value regardless of origin, and hence does not require segregation of batches.

The three kinds of lines differ as to ownership, operation, and regulation. A crude-oil line or a products line may be owned by one company or jointly by several oil companies. However, liquid lines and gas lines are separate industries. Rarely have they any corporate connections. They are different industries. Their regulation falls under different federal bodies. Liquid lines come under jurisdiction of the Interstate Commerce Commission, while natural-gas lines answer to the Federal Power Commission. With few exceptions, liquid pipelines are common carriers, even though a line was built by one or more cooperating companies primarily for its or their own use. Common-carrier managements must post tariffs and accept for shipment products offered for transmission by other companies in accordance with tariff conditions. Curiously, however, a crude-oil pipeline company does not necessarily deliver to a customer the identical product provided by the shipper for that customer. It is sometimes more expedient for a pipeline company to supply the proper quantity of a product of the same quality, but from a different batch, perhaps already in storage at the delivery end of the system.

Development of Pipelines

Pipelines had their beginning just a little short of a century ago, under most difficult—even bloody—circumstances. When Edwin L. Drake drilled his famous oil well near Oil City in northwestern Pennsylvania in 1859, the need for pipelines was born. The Drake-initiated oil boom occurred along Oil Creek in a rough terrain several miles from a railroad. After futilely trying various ways of transporting the oil by water on the shallow and sometimes almost dry streams, it was hauled to the railheads in barrels on wagons, at costs of three dollars to five dollars per barrel for the 20- to 25-mile trip. (Today, the charge for moving a barrel of crude oil 650 miles from Tulsa to Chicago by pipeline is only about 40 cents, and includes a gathering charge.) Oil cartage in the 1860's quickly grew into a huge, fiercely competitive business, which at its peak in a few years employed several thousand teamsters.

Wagon haulage was obviously not the answer to the oil-transportation problem, but with teamsters making $30 per day instead of the customary two dollars, the method was not easy to supplant. In 1861, an attempt was made to build an oil pipeline, using wood pipe. "An attempt," we say, because at night the irate teamsters dug up the pipe laid during the day. Open fighting and bloodshed resulted.

Progress, however, was not to be denied. In 1865 Samuel Van Syckel built the first successful crude-oil line, of wrought-iron pipe, two inches in diameter and five miles long, from Pithole City to Miller's Farm, in western Pennsylvania. Three steam-driven pumps, in two stations, provided a pressure of 200 psi to give the line a capacity of 800 barrels per day, equal to 300 teams of horses working ten hours per day. Construction of this line was not easy. Two crews were required. One to build the line; the other to look after the angry wagon men.

Teamsters were not the only hindrance. At first, railroads were pleased—initially pipelines involved more freight revenue, i.e., pipe as well as products—but when they began to realize the import of pipelines their delight turned to dismay. Here was new competitive transportation, which the railroads were not disposed to accept without a struggle. They fought pipelines by every device available. They refused to grant permission to lay pipe under their tracks. On at least one occasion a line laid closely parallel to railroad tracks was pulled out of the ground at night with chains by locomotives. When it was necessary to enact legislation covering this new form of transport, railroads, barge companies, and teamsters presented powerful lobbying influences against it.

However, pipelines were too strongly supported by economics for growth to be stopped by violent or legal means. In 1874 a "long" line of four-inch pipe was built 60 miles to Pittsburgh by Dr. Hostetter, a patent-medicine manufacturer. (Early interest in oil was not as a fuel but as medicine. Crude oil was sold in bottles at prices from 50 cents to one dollar a half pint, under various names such as Indian Rock Oil, purporting to be a cure for virtually every human ailment from corns to lumbago.) In 1879 the first pipeline crossing of the

Before a pipe is laid in its trench carved in the countryside, it is cleaned, coated with enamel, and wrapped with layers of glass fiber and asbestos felt. This is the Rancho Pipe Line of Shell Oil Company.

mountains was made by a six-inch pipe from Coryville, Pennsylvania, to Williamsport, Pennsylvania; it was extended nine years later to Bayonne, New Jersey. This line was built in 17-foot lengths of wrought-iron pipe, with thread-connected couplings.

Oil lines continued to fan out from the Pennsylvania oil fields, growing in size and length, until by 1900 the lines totaled about 18 000 miles. Then, in 1901 came the Lucas gusher in the fabulous Spindletop field of Texas—and with it a crude-oil transportation problem of a completely different magnitude. The oil fields of Texas and adjoining states are 1000 to 1500 miles from the big consuming markets of Chicago and the East. The first crude-oil trunk lines spread from the Texas fields to tidewater where tankers took over. Tankers are still the lowest cost method of oil transport between the Gulf and East coasts, which accounts for the 630 million barrels they hauled in 1951, or about 95 percent of the oil moved from Gulf ports to the Eastern Seaboard.

On the other hand, railroad tank cars cannot compete with a pipeline, if one is available. Between two points the tariff for shipment of oil by pipeline averages about 35 percent of that by rail. Hence for inland areas, pipelines soon manifested their economic advantage over rail delivery. As to petroleum-line growth (counting both gathering and trunk systems) mileage in 1910 had risen to about 40 000; by 1920, to 53 000; and by 1930, to 110 000. Pipelines continued to grow even during the depression years so that by 1940 about 124 000 miles of pipe were carrying crude oil and refined products. The havoc caused among tankers by Nazi submarines placed a stupendous burden on pipelines—and every other form of oil transport. As a matter of extreme national emergency, and with triple A priority, the famous Big-Inch (24-inch) crude line was built a distance of 1254 miles from Longview, Texas to Phoenixville, Pennsylvania. It was soon followed by the 1477-mile Little Big Inch (20-inch) for transportation of refined products over an essentially parallel route. Both lines used electric power for pumping. So efficient was their operation that they consumed only a nickel's worth of electricity for each barrel of oil or product transported from Texas to the Atlantic Seaboard. These two lines have since been converted to natural gas (but can, in a national emergency, be again modified for liquid flow in 90 days). At war's end, 140 000 miles of crude and products lines were in service. This figure has since risen to about 163 000, including about 12 000 miles of petroleum lines laid in the last two years. Some 21 550 additional miles of liquid and gas lines are under construction or planned.

Products lines date from 1901 when a pair of four- and five-inch lines, originally built to convey crude oil from Titusville to Wilkes Barre in Pennsylvania, were converted for the movement of kerosene. However, products lines grew slowly until about 1930, when the total reached only 1300 miles. Growth since then has been rapid: approximately 8040 miles in 1940; 22 000 in 1950; and 24 000 miles, now, with 4760 miles more on the way.

Of the three kinds of pipelines—crude-oil, products, and natural gas—gas lines have the longest history. Actually the Chinese seem to have begun it (unless the Russians did it!). Many centuries ago the Chinese transported natural gas in bamboo pipes—they still do in fact—for evaporating water from brine to obtain salt. In several regions in this country natural gas was piped locally for illumination, beginning as early as 1821 in Fredonia, New York. The first "long-dis-

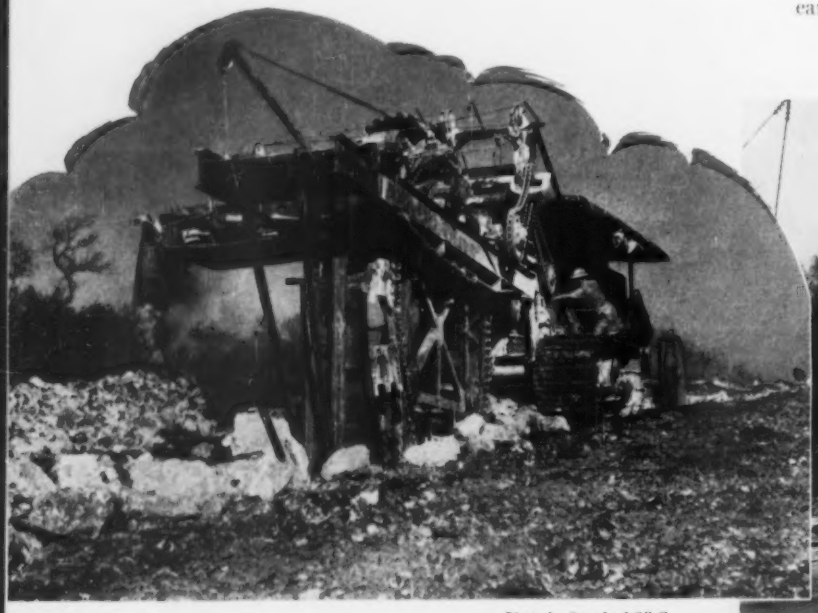
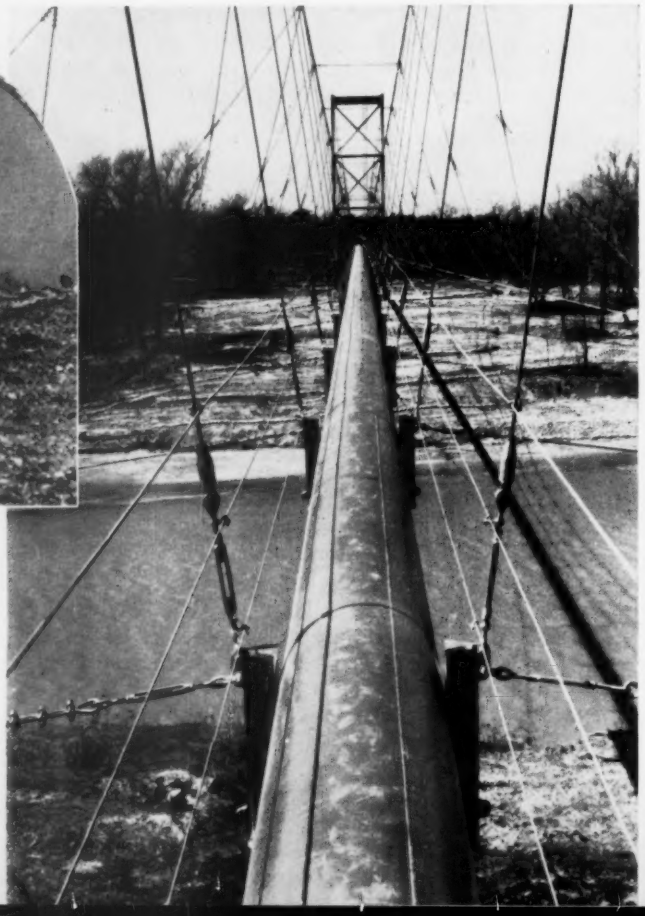


Photo by Standard Oil Co.

Photo by American Gas Association



Without the earth-handling machines (above) modern pipelines simply wouldn't be. This digger is cutting a trench for an 18-inch line for Humble Pipe Line Company. Right—A line of the Transcontinental Gas Pipe Line Corporation crosses the Brazos River overhead.

tance" gas pipeline was built in 1870 to carry gas 25 miles from West Bloomfield, New York, to Rochester, New York. However, the pipe, consisting of eight-inch holes bored in white-pine logs, was a failure.

Iron pipe was first used for gas lines in 1872, when a two-inch pipe was laid for 5½ miles between Newton Wells and Titusville in Pennsylvania. The year 1891 marked the beginning of modern high-pressure gas lines. Two lines of eight-inch pipe operating under 525 psi carried natural gas 120 miles from the fields in northern Indiana to Chicago. However, the total mileage of natural-gas lines in 1900 was small. Gas lines, like liquid-products lines, have had their real growth since 1931. The modern gas pipeline began in 1931 with the laying of thin-wall, high-strength, 24-inch pipe a distance of 900 miles from Texas to Chicago. The first pipeline to bring natural gas from the Southwest to the Eastern markets was a 24-inch line built in 1944. Gas lines at the end of 1952 totaled about 342 500 miles for gathering, transmission, and distribution, with 13 500 miles planned.

Technical Developments Behind the Pipelines

Pipes possess some qualities that give them an inherent edge over other modes of transporting oil and gas. However, pipeline systems have become what they are largely because the industry has drawn heavily on a wide variety of technical advances in other fields.

Take pipe itself, for example. One shudders at the thought of early pipeliners trying to use wood pipe. The inadequacy of this material led to the use of cast-iron pipe, which, while far more successful, left much to be desired. Wrought-iron pipe, which followed in about 1830, was much lighter, much tougher, and made possible screw joints. Steel pipe followed about 1887 and paved the way for high pressures essential to economic operation of long lines.

Steel manufacturers have continuously improved the quality of steel pipe. Today's lines are laid of high-strength steel pipe. The wall thickness of high-strength pipe, for example, measures from about 0.250 to 0.5 inch. Pipe thicknesses have remained relatively constant. As line pressures have increased pipe manufacturers have found ways to increase pipe strength without appreciable change in pipe thickness. Another great advance came in the 1920's with the development of large-sized seamless and electric-welded pipe for this application.

Consideration is being given to pipe of material other than steel. Aluminum alloy and plastic, for example. These would have the obvious merit of being lighter to handle, but the problems of strength and cost yet remain to be solved.

Pipe lengths have increased. Early pipes were from 10 to 20 feet long. Now even the largest diameters come in 40-foot sections, and smaller pipes are in lengths up to 60 feet, with obvious economies in the laying operation.

The early cast pipes were joined with lead. The results ranged from poor to failure. For years, wrought pipe and, later, steel pipe were joined by screw fittings. These were quite successful, but hard to lay with hand labor. About 1920 oxy-acetylene welding came into vogue, which in turn was replaced about 1928 by electric-arc welding, now the universal method. Welds on larger pipe are usually made in three or four passes, with the welder "signing" his work with his special mark. Selected joints are radioactively inspected for soundness. River crossings or any points of high stress are inspected by x-ray methods. Because this welding operation is so vital, only the most skilled welders are employed. It is not uncommon to release a welder who has a record of two bad joints because a poor joint can have serious consequences.

The modern pipeline would not be possible without the bulldozer and related machinery, and the various equipment specially built for pipelining. Machines for screwing pipe together came in 1912. Until about 1924 trenches were dug with picks and shovels; pipe was moved into position by strong backs. This is no longer possible either physically or economically. A 40-foot section of 26-inch, high-strength line pipe weighs about 2¾ tons. It may go into a trench on top of a mountain, and it may have to be bent to fit the contour of the ground. No jobs these for hand labor. The modern ditching machine is capable of digging a trench 7½ feet deep, 4 feet wide, and is equal to the best 300-man pick-and-shovel crew. Specially adapted power-driven tools bend the heavy pipe, move it into position, coat and wrap it, lower into position, and back-fill the trench.

A "go devil" or scraper is inserted in a line at Akron, Ala. Photo by Standard Oil Company.

The most important, specially contrived machines in the pipe-laying business are those for cleaning, coating and wrapping the pipe before it is lowered into the trench. Life of buried pipe is now greatly lengthened by various coating techniques that deter rusting and other chemical attack. The cleaning and coating machines are self-propelled and automatically clean the pipe, apply a thick layer of hot tar, asphalt, or plastic, and follow this with two or three tight wrappings of wide asbestos paper or glass-fiber tape. The many specially developed machines and techniques made possible, for example, the recent laying of the 26-inch oil pipe for the West Texas Gulf Pipe Line Company for 465 miles across the flat Texas prairie at the rate of 1⅓ miles per day.

Railroad and highway authorities demand that pipelines crossing a railroad or hard-surfaced highway be contained in

a conductor pipe. This safety precaution prevents petroleum liquid or gas from leaking up into the public thoroughfare should a fracture occur in the crossing. The conductor pipe or casing (pipeline parlance) is sealed with special rubber rings in the annular space at its ends. Small vent pipes are installed as vertical runs in the casing close to the seal points.

Crossing a river is something else again. Particularly the large, temperamental rivers such as the Mississippi, or those with swift currents or tides. Each of these becomes a special problem calling for the utmost in engineering skill. Frequently a crossing, either submarine or overhead, is made with several small pipes instead of one large one. For narrow streams the pipe is generally welded and coated on shore and then pulled across the stream bed into a prepared trench, which is then back filled. When this is not possible, pipe sections are joined and coated on barges and eased overboard to the bottom.

Pumping stations have undergone a metamorphosis. The early pumping stations used the only type of prime mover available—the steam engine. This later gave way to the horizontal air-injection oil engines, and these, in turn, to the vertical solid-injection diesels of large horsepower and high efficiency. Dual-fuel engines, utilizing either gas or oil and high-compression gas engines, are now in use.

On most gas lines pumping is done with reciprocating gas-engine units, which are built in sizes up to 2400 hp. Station spacing on gas lines has shown a tendency to decrease, from an average of perhaps 100 miles, many years ago, to 75 miles and frequently less. In gas pumping, more frequent but smaller pressure boosts are desirable economically.

The newcomer in the drive family is the gas turbine which, while young, already shows great promise, particularly for gas-line pumping. The gas turbine is described in more detail on pages 152–4.

The trend in crude and products lines is strongly toward electric-drive in pump stations using electric-utility power. Several factors lie behind this. The trend is possible, of course, only because electric power is becoming more and more available to the widely separated and often isolated stations.

Choice of drive is inevitably one of cost. Motors are at a disadvantage compared to engines because electric power costs more than fuel, but with liquid and gas fuel rising in value this disadvantage is declining. Electric motors have two strong factors in their favor. Automatic and remote controls of the many functions of a pumping station are far more practicable with motors than with engine drive. Also motorized stations require much less manpower. It is not uncommon for a pumping station of, say, three or four modern diesel-driven units totaling 4000 to 6000 hp, to have a staff of 15 to 20 men for three-shift operations. The personnel required for a comparable electric-motor station is about six or seven. Motors, too, obviously, require much less maintenance than do reciprocating engines.

Some Aspects of Pipeline Operation

Relatively little needs to be done to crude oil, refinery products, or natural gas to prepare them for trunk-line transmission. A few fields produce "sour gas," meaning it has a high sulphur content. It is customary to pass such gas through scrubbers to remove hydrogen sulphide and water vapor. If not removed, the resulting sulphuric acid, formed during transmission, can cause serious corrosion to the pipe. Also it is necessary to remove from "wet" gas those hydrocarbon fractions that would liquefy in the line under the pressures and temperatures that occur in pipeline operation.

To minimize internal corrosion in liquid lines, inhibitors are generally added to the refined product before it is introduced into the trunk line. To prevent external corrosion by electrolysis, widespread use is made of cathodic protection. A low potential is maintained between pipe and earth, usually by static rectifiers of the copper-oxide type, in such a way that the metal is always cathodic with respect to the soil. Thus where pipe is buried in the soil, currents always flow into it, never from it.

In operation of products lines it is essential that individual consignments keep their identity. Frequently a products line contains throughout its length many batches differing as to type, grade, and ownership: gasoline, kerosene, diesel fuel, heating oil, and so on. One representative long products line has been known to be moving 65 different batches at one time. These products are simply introduced into the line one behind the other, each pushing along the one ahead of it. Surprisingly, the amount of mixing is negligible. Even in a 1000-mile run of a 12-inch line the intermixing that requires isolation at the receiving end amounts to only 400 or 500 barrels—or in, say, a 16-inch line the intermixing is spread over 1700 feet. This mix is, of course, not thrown away, but is added to other products in non-detrimental quantities.

To keep the quantity of intermix inconsequential, the location of the interfaces must be accurately known at all times. At the delivery end of a 1500-mile line all the interface mixture, moving about four miles per hour, passes a valve position in a few minutes. Thus, valve operations must be timed

Interesting Facts About Pipelines

The average rate of flow for crude oil and most refinery products is three to five miles per hour. Gas travels faster, 15 to 25 mph.

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The standard unit of petroleum volume is the 42-gallon barrel. This began as wooden casks, nominally containing 40 gallons, but with two additional gallons allowed "for give."

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To handle by rail the gasoline carried 600 miles by a single, 12-inch pipeline in one day would require 4330 tank cars. Thus to try to haul by rail the oil and refined products carried by pipelines would result in hopeless rail congestion.

The construction of a pipeline from Texas to Ohio, as a representative example, required the obtaining of rights-of-way across 3000 separate pieces of land, some of which had as many as 25 owners, with specific, written approval necessary from every one.

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Suppose the filling of a 20-inch oil line in Texas is started. Two million barrels and two weeks later oil begins arriving at the New Jersey terminal.

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It is customary in the operation of oil lines periodically to clean them by sending a "pig" through with the product. This is a device consisting of scrapers and heavy brushes that scrape the pipe interior clean of scale or petroleum deposit. The pig and the scrapings are pushed on through from one station to the next by the pressure of the fluid behind. The object is to maintain the smooth interior necessary for minimum fluid resistance and least pumping power.

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When a pipe develops a badly corroded spot it is repaired by welding a steel plate over it—while the line is carrying oil. While this seems to be a hazardous procedure, it is done routinely. The welder is equipped with clothing that can be shed in an instant if oil breaks through and sets him on fire.

to a few seconds to keep delivered products separate and to avoid having a shipment of, say, high-octane gasoline contaminated with kerosene, or diesel fuel.

A well-coordinated communication and dispatching system is essential. This is one reason the pipeline industry has been the first to adopt the newest method of communication—microwave. Also, some pipeline companies are experimenting with a new way to track the passage of their silent freight. A small amount of a radioactive isotope produced in an atomic pile is introduced into the beginning of each product as it is started through the line. Antimony^{124} is such an isotope with a half life of 60 days, long enough to make the trip but brief enough to disappear shortly thereafter. Thus the progress of an interface is detected by radiation counters located at appropriate points along the line and at pumping stations. This method, by comparison with the usual methods, such as periodic sampling of the flow to measure viscosity is simple and automatic.

Both liquid- and gas-line operators have problems of product storage at the delivery end. But their problems differ completely. Liquid products are stored in large metal tanks located on the familiar tank farms. Gas volumes, on the other hand, are far too great for any practical amount of tanks to take up the slack between the fairly uniform flow necessary for pipeline economy and the highly variable seasonal heating demand. This has led to growing use, in regions of high gas consumption, of exhausted natural gas and oil wells, mines, salt domes, and other underground areas as natural-gas storage reservoirs. At the beginning of the 1952–53 heating season, 700 billion cubic feet of natural gas was in underground storage—or approximately one fifth of the nation's annual natural-gas usage. It would take about 40 000 of the largest size gas holders to store this amount.

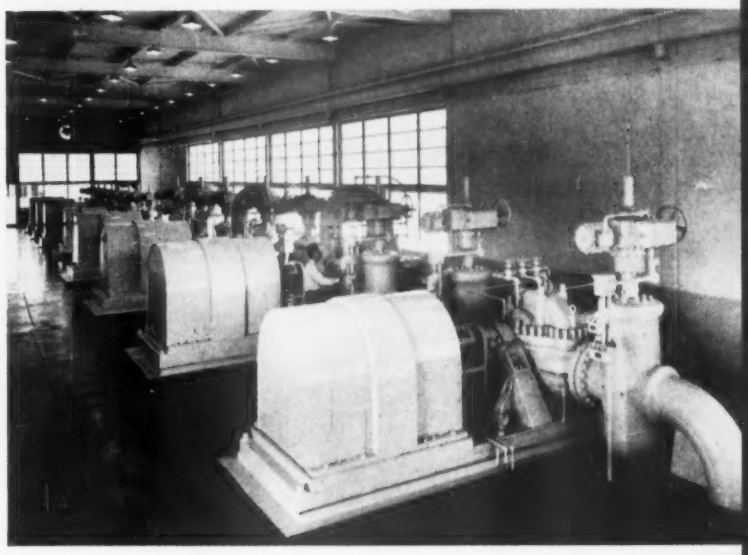
Trends in Pipelining

Aside from the most obvious fact that pipeline systems of all three types are growing at an unprecedented rate, several other trends are in evidence. Pipe sizes—both maximum and average—continue to increase. In 1936 only one fourth of the 57 820 miles of crude-oil trunk-line pipelines were larger than eight inches in diameter, and, except for an 80-mile section, 12 inches was the largest. In 1950, about 40 percent of the 71 373 miles of pipe exceeded eight inches in diameter, and for nearly 5000 miles of this the pipe was bigger than 12 inches. The largest liquid line in service in the United States six years ago was one of 24 inches. The West Texas Gulf Company's line, dedicated in May, has a diameter of 26 inches, which makes it the largest diameter liquid line in North America, although a 30-inch line is under construction in Wisconsin. (The largest oil lines in the world are the 1067-mile Trans-Arabian line comprised of 30- and 31-inch pipe, and the 30- and 32-inch Iraq Petroleum Company lines.) The largest major gas line is one of 34 inches, whereas ten years ago 26 inches was the top. Gas lines of 30-inch pipe are common; a few are 34 inches.

The trend in oil-line pressures has risen from 600 to 700 psi in 1935 to 1000 psi in 1950, with a few lines operating at 1400 to 1500 psi. Operating pipe stresses are up from 15 000 psi in 1935 to 35 000 psi in 1950. Operating pressures of 750 and 850 psi are now common to gas pipelines and some long lines are now being designed and built to operate at 1000 psi.

The motive, of course, is economics. But before economic forces could prevail there had to come the outstanding developments in pipe manufacture to make these enormous pipes possible. That is a tremendous story in itself. The economics of bigger pipe is obvious. An economically balanced 20- or 24-inch line, running at full load, can move oil for barrel-mile costs of only 45 and 36 percent, respectively, of the equivalent full-load costs in a ten-inch line.

The trend for more fully automatic or remote control of stations is conspicuous. This is an outgrowth of numerous developments in electrical controls, the greater use of electric-driven pumps and compressors, which lend themselves better to remote, automatic controls than engine drives, and to the desire for centralized control. This type of operation is dramatized by the fact that the pumps in the stations of a Shell products line in Ohio are remotely operated by a dispatcher in Rockefeller Center in New York City.



Force-ventilated motors in Wortham Station of West Texas Gulf pipeline. Four 1500 hp, four 1000 hp, and three smaller ones, give a total of 11 550 hp, making it the world's largest electrified station.

The unattended pumping station is today's number-one topic among pipeliners. Automatic controls have been developed for every foreseeable contingency and these have proved reliable. True, most pipeline people are still a little nervous about having an expensive pumping station, perhaps a few hundred miles away, running with no human attention. And the possible economic loss from a station out of service—remembering always the nature of its freight—is so great as to inspire conservatism. However, several stations are operating under automatic or remote control with only "watchman" attendance. Many, if not most, pipeline men believe that unattended stations are not far in the future for booster stations where there are no delivery operations requiring personnel. In fact, as this is written, one project is going into service with completely unattended booster stations under remote supervisory control over microwave. Meanwhile, more and more operations in attended stations are becoming automatic or remotely controlled.

Almost without the layman realizing it, the surface of our nation has been underlaced with a web of pipelines, a network that has become an indispensable part of our economy. Pipelines have become a major, highly specialized transportation system, one that has been quick to adopt new developments, and one that in growth is outstripping all others.

Gas Turbines for Pipelines

The gas turbine continues the family of illustrious prime movers Westinghouse has supplied the pipeline industry for half a century. This began with the gas engine, developed by George Westinghouse himself at the turn of the century, some of which are still operating with high success. Others are steam turbines and synchronous and induction motors. All have their places.

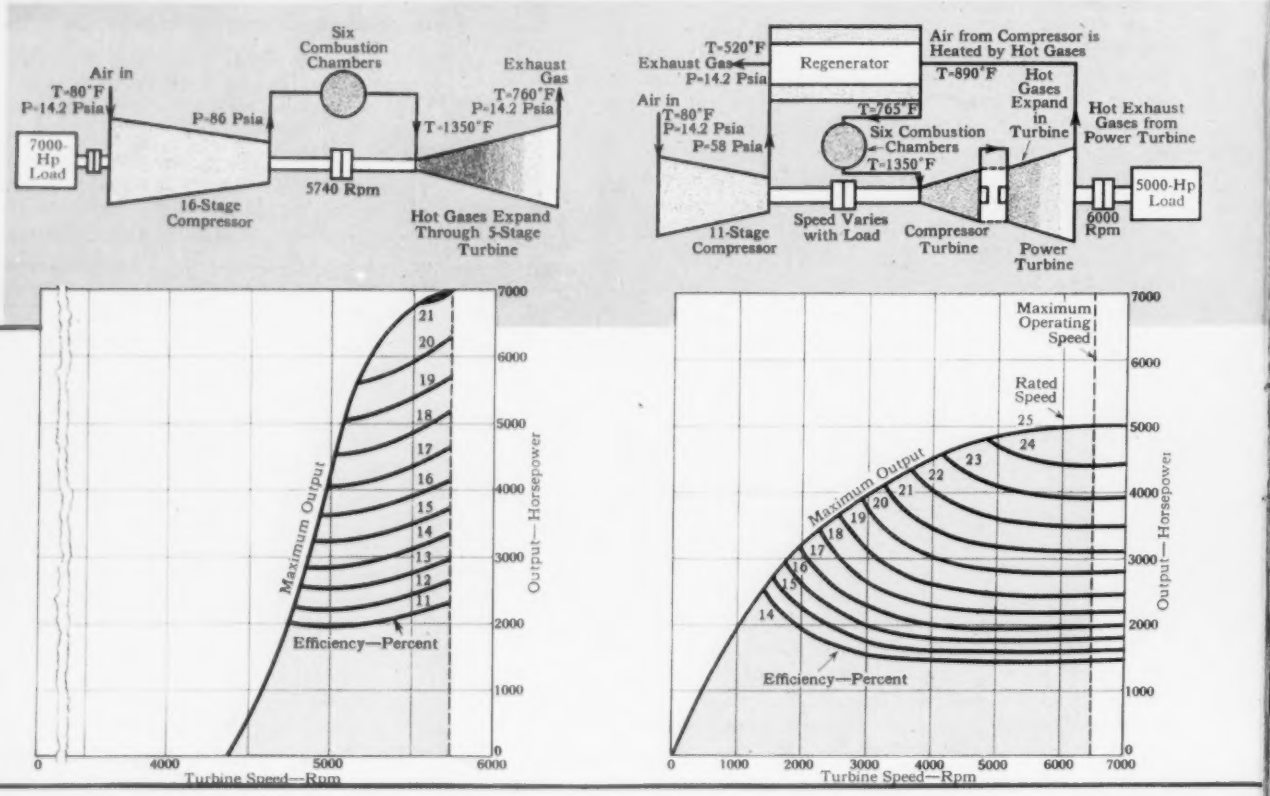
T. J. Putz, *Manager, Gas Turbine Engineering, Steam Division, Westinghouse Elec. Corp., South Philadelphia, Pa.*

Pipeline transportation of liquid and gaseous fuels has become an important factor in supplying the energy requirements of the United States. This type of fuel transportation requires a large amount of horsepower to drive compressors and pumps. The gas turbine can draw its fuel from the line it serves. Also, it can be installed at the optimum location on the pipeline since it can be arranged to operate without water or outside power source. These qualities make the gas turbine a superlative power plant for supplying compressor and pump horsepower on gas and liquid pipelines.

Westinghouse has built two types of gas turbines for pipeline service. One is the open-cycle, single-shaft unit in horsepower sizes of 1800 and 7000. This type is most suitable for base-load operation when the cost of available liquid or gas fuel is low, and for peaking service when the fuel cost is high. The second turbine, under construction, is an open-cycle, two-shaft arrangement with regenerator. This type utilizes some of the waste heat to improve efficiency and provides a high degree of flexibility in speed and load. It is being built in the 5000-hp size.

It was on May 26, 1949 that Westinghouse placed an 1800-hp gas turbine in operation in a compressor station at Wilmar, Arkansas. This was the first commercial gas turbine in the United States to burn natural gas, and the first installation in the world of a gas-turbine power plant driving a centrifugal compressor for natural-gas transmission. The initial installation of this new type of power plant was at Wilmar, Arkansas on the 22-inch line of the Mississippi River Fuel Corporation connecting Monroe, Louisiana, with St. Louis, Missouri. Later, when line conditions changed, the unit was moved to its present location at Bonne Terre, Missouri.

As of July 1st, the 1800-hp gas-turbine power plant has accumulated more than 13 000 hours of "on-the-line" operation. This experience has been sufficient to give heavy



evidence on the suitability of this new type of prime mover for pipeline service. Starting the unit is a simple matter. It has frequently been started and placed in service in less than ten minutes. In a plant designed for remote starting of the unit, all functions necessary for start-up could be accomplished from remote pushbuttons, and with fewer men than are required for starting a reciprocating engine. It is certain that a gas-turbine-drive station could be operated with less manpower than a conventional engine-drive station of equal rating. The lubricating-oil consumption has been essentially nil—less than one gallon per week—and no water is required. The turbine can be operated at full load continuously for protracted periods. Necessary maintenance can be limited to scheduled yearly inspection.

This turbine has been fitted with dual nozzles to permit burning either gas or liquid fuel. Switchovers from one type of fuel to the other have been made without removing load. It was originally thought that the combustion flame tube and nozzles might be two items requiring periodic maintenance. However, the unit is still running with the original flame tubes and nozzles.

The expectation of low first cost has been confirmed. The installed first cost of this station was only two-thirds of the cost per brake horsepower of a new reciprocating station built by this same company during the same time. Contributing to this economy are the low foundation cost and other building economies possible with the gas turbine. A record of the actual costs per day of operating this simple plant compared to those of reciprocating engines in adjoining stations shows that the gas turbine consumed $62.50 worth of gas, and the gas engine required $44.50. Offsetting this, however, is the turbine's consumption of but 15 cents' worth of lubricating oil and no water, while the engine requirement

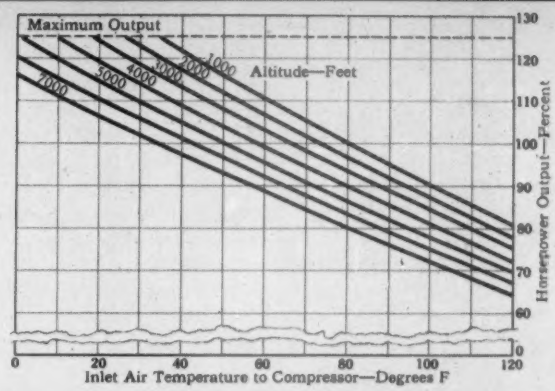
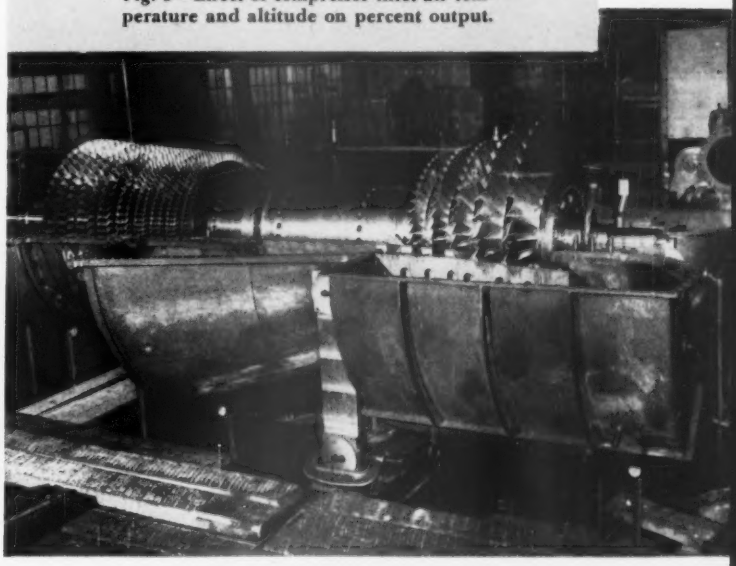
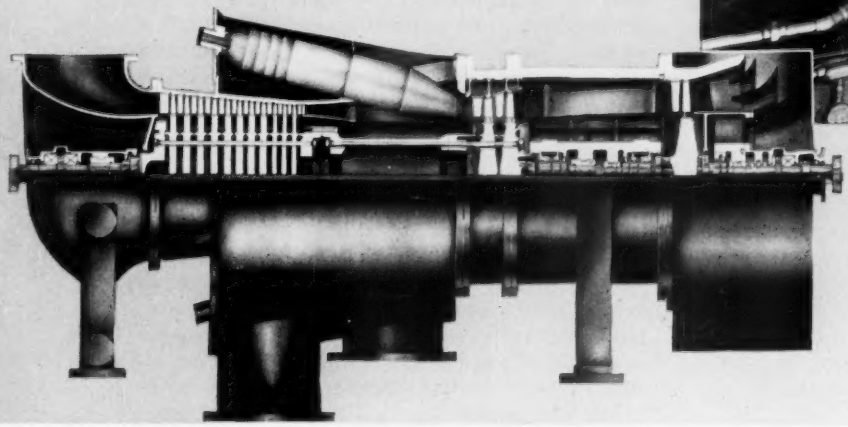


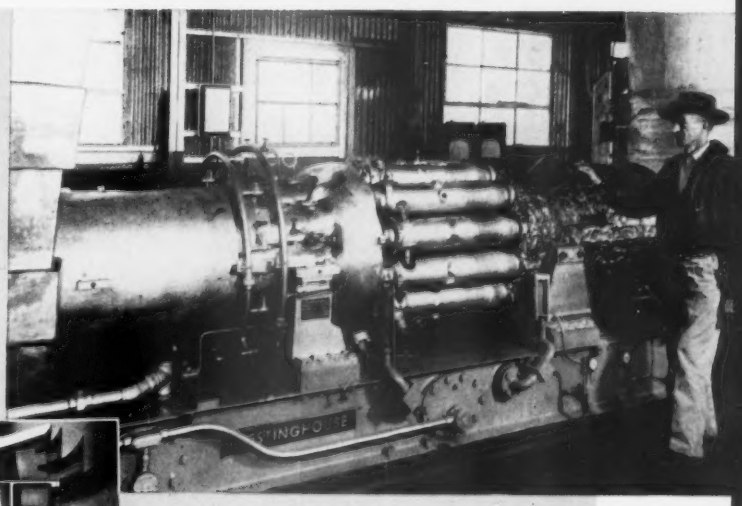
Fig. 3—Effect of compressor inlet air temperature and altitude on percent output.



Figs. 1 and 2—Performance characteristics and general arrangement of a 7000-hp, single-shaft gas turbine and a 5000-hp, dual-shaft unit. When the turbine drives both the compressor and the load, as speed drops the power available drops, becoming zero at 4400 rpm. When the compressor and load are driven by separate turbines, greater load-speed flexibility is obtained. The characteristics become similar to that of a steam turbine.

A 5000-hp open-cycle gas turbine with regenerator for economy and separate turbines for compressor and load for operating flexibility.





(Top photo) A 7000-hp, single-shaft gas turbine now operating in Texas. (Below) An 1800-hp gas turbine in booster station of the Mississippi River Fuel Corporation.

for oil totaled $9.80, and for water $5.75. The electric-power requirements also slightly favor the turbine: $5 as against $5.95. The total costs per day of these services are $67.65 for the turbine and $66 for the engine. The combined first cost, utilities cost, and operating labor costs have been found to be substantially lower than a reciprocating engine plant. One must remember this in comparing a prototype gas turbine with a well-developed reciprocating engine. The experience gained from the operation of this unit shows that the gas turbine is well suited for pipeline service.

The 7000-hp size of this type was first placed in commercial service at Fort Stockton, Texas on November 26, 1952, burning natural gas fuel. This machine, as of July, has accumulated 2500 hours of service. Operation has been continuous except for a shutdown to make repairs, caused by a failure in control during start-up following an inspection.

The 7000-hp unit was designed to incorporate improvements suggested by experience with the 1800-hp prototype machine and to make it possible to build and maintain at lower cost. The cylinder of the compressor, combustor and turbine is built with sufficient strength to maintain the alignment of the rotating parts. This eliminates the need for any additional bedplate under the combined unit. For ease of maintenance a single horizontal joint runs the length of the entire unit. When the upper half of the casing is lifted, all rotor and stator elements are exposed. The compressor and turbine rotor are constructed as a single unit with two end bearings mounted on, but external to the cylinders. The turbine rotor is built up of disks held together by bolts. The tapered, twisted rotating blades of turbine and compressor are profile tipped and mounted on axial entry roots. The stationary turbine diaphragms are held in the blade rings

Electricity's Contribution to

MERRITT HYDE
Pipeline Electrification Engineer
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Fig. 1—Shipments are accumulated here in 37 tanks, totaling more than 2 000 000 barrels' capacity, for a major trunk products line.

EACH YEAR in the United States about 2½ billion barrels of oil are moved from half a million producing wells, through some 350 refineries, and the resultant products distributed throughout the nation. Pipelines do a large part of this transportation job—well over 100 billion ton-miles last year—with about 150 000 miles of crude-oil lines (including some 70 000 miles of gathering lines) and more than 25 000 miles of lines carrying refined products, as of early 1953.

In the performance of this task electric power and electrical control are playing an ever-increasing part. While engine power has long predominated in this field because of the ready availability of low-cost fuel, constant extension of electric-service facilities has made electric power available to more and more pump station sites at a competitive level, considering the lower capital cost of motorized stations. The trend is augmented by increasing realization of the advantages of electrical control for efficient station operation. As one authority has put it:[1]

"Some of the latest stations incorporate the use of sequence relay controllers that do everything except the employe's homework. For example, in the new Ozark system stations, which use two 1500- and one 750-hp motor-driven pumps to deliver about 275 000 barrels of crude oil daily, the mere pressing of three buttons on the console by a single employe will cause the automatic performance of 12 operations in six minutes, which would otherwise take two or three husky men an hour to accomplish. This means a great time-saving during a service shutdown and start-up. With a revenue of $75 per minute depending on getting the line under way, the direct saving to be gained by a $10 000 investment in sequence control is obvious. Perhaps even more important, however, is the insurance of a foolproof job of starting. Any group of men having 12 critical operations to be performed in a required sequence can easily make an error that might cause an accident and further losses."

The first pipeline used less than ten horsepower for the

mounted in peripheral grooves. The turbine cylinder and rotor are air cooled, allowing a reduction in the amount of critical material.

In addition, this construction lowers the temperature of external surfaces. The external turbine surfaces are subjected only to the low exhaust temperature (approximately 700 degrees F) of the turbine. The combustion system incorporates the desirable features of the annular combustors developed for aviation gas turbines and of the can-type design used in the prototype 1800-hp unit. The conical, single combustor casing requires no expansion joints or external hot connections. To facilitate maintenance and assure good combustion efficiency, can-type burners are mounted into the single conical combustion housing so that removing one cover exposes them for maintenance.

The 5000-hp compound, open-cycle unit is now being erected in the shops for test. This unit differs from the single-shaft unit in two respects: First, a regenerator is added to utilize some of the waste heat leaving the turbine exhaust to preheat the air for combustion. Second, the power turbine is mechanically independent of the compressor and its turbine.

The addition of a regenerator increases the thermal efficiency as it recovers about 75 percent of the available exhaust heat. It is, however, a large and heavy element, weighing about five times that of the gas-turbine power plant itself.

The divided shaft also adds to the complexity. The net result is that the total cost of the dual-shaft unit per horsepower is about 40 percent more than for the single-shaft machine. This additional cost and complication are justified when fuel costs are high and the greater flexibility of operation provided by the dual-shaft can be utilized to advantage on lines with large variation in gas flow.

Modern Pipelining

Motors—in sizes up to the largest built for use in hazardous locations, electrical controls, microwave, supervisory control, mechanical-electrical pressure devices—these are but some of the tools being provided by the electrical engineer to the pipeliner.

pumps at each of its two stations. Today the largest pumps in oil-pipeline service are two 6000-hp centrifugal units, steam-turbine driven, at Arabian American Oil Company's Abqaiq pump station No. 4—the initial station of the Trans-Arabian pipeline. Either can deliver full line throughput—as much as 400 000 barrels daily—at 800-psi discharge pressure. Electrically driven centrifugal installations range up to 3000 hp per unit, with larger sizes actively contemplated. Operation of centrifugal pumps at speeds above 3600 rpm by step-up gear appears economically interesting in large capacities. A parallel situation exists in gas-line pumping, where motor-driven units have thus far not exceeded 3600 rpm, in contrast to gas-turbine drives operating as high as 8700 rpm.

Largest electrified petroleum line, and "biggest-inch" oil line in North America is the West Texas Gulf Pipe Line, a 26-inch crude-petroleum carrier. It was completed in 1953 by five participating companies to obtain the economy of large-line operation. It runs 465 miles across Texas from Colorado City to Beaumont, with a 20-inch spur extending 112 miles northeast from Wortham to Longview where it delivers to the Mid Valley pipeline, a 20-/22-incher running 1053 miles to Ohio. With additional partial booster stations now under construction, the line will have a daily capacity of 381 000 barrels, which can be increased to 440 000 barrels ultimately by an increase in booster capacity. Wortham station has 9550 hp in main-line pumps, making it the largest electrically powered petroleum pumping station.

Products-line installations range up to 18 inches in diameter, 432 miles of this size being used in the Plantation Pipe Line system from Baton Rouge, Louisiana, as far as Bremen, Georgia. This pipe parallels an earlier 12-inch line. From Bremen through Atlanta to Greensboro, North Carolina, the system consists of two lines of 14-inch and 10-inch diameters. Baton Rouge, largest station pumping refined products, contains 6300 hp in motor-driven main-line pumps. Four branch lines serve Birmingham and Montgomery (Alabama), Columbus and Macon (Georgia), and Chattanooga and Knoxville (Tennessee). Totaling 1967 miles of pipe, and with 22 pumping stations, employing some 60 000 hp in main units, this system has a capacity in excess of 220 000 barrels per day of gasoline. It delivers refined products in the form of gasoline (third-grade, regular, and premium) tractor fuel, kerosene, diesel fuel, and light heating oil, in separate batches for 14 shippers, to 18 terminals on its main lines and laterals.

Large-diameter pipeline installations were logical for natural-gas transmission, and pipe now in such use ranges up to 34 inches in diameter. One of the largest of the natural-gas transporters and biggest user of electric power in this service is Texas Eastern Transmission Corporation. That company was the successful bidder in 1947 for the purchase of the Big-Inch and Little-Big-Inch lines, which War Assets Administration had put up for sale.

The Big- and Little-Big-Inch lines were built during World War II by the government for the transportation of petroleum and petroleum products. The Big-Inch line, which was used to move crude petroleum, consisted primarily of a 24-inch transmission line extending from Longview, Texas, in a northeasterly direction for more than 1200 miles to Phoenixville, Pennsylvania. The Little-Big-Inch line was used to move petroleum products from Gulf Coast refineries to the East Coast. It consisted principally of a 20-inch transmission line extending almost 1500 miles from Beaumont, Texas, to Linden, New Jersey. The two lines converge near Little Rock, Arkansas, and run parallel from that point to Linden.

Texas Eastern started transmitting gas through the lines in May, 1947, and immediately started a construction program to raise their capacity. This program resulted in the construction of 21 compressor stations, of which seven were the conventional reciprocating gas-engine type and 14 were of the new electrically driven centrifugal type. The centrifugal

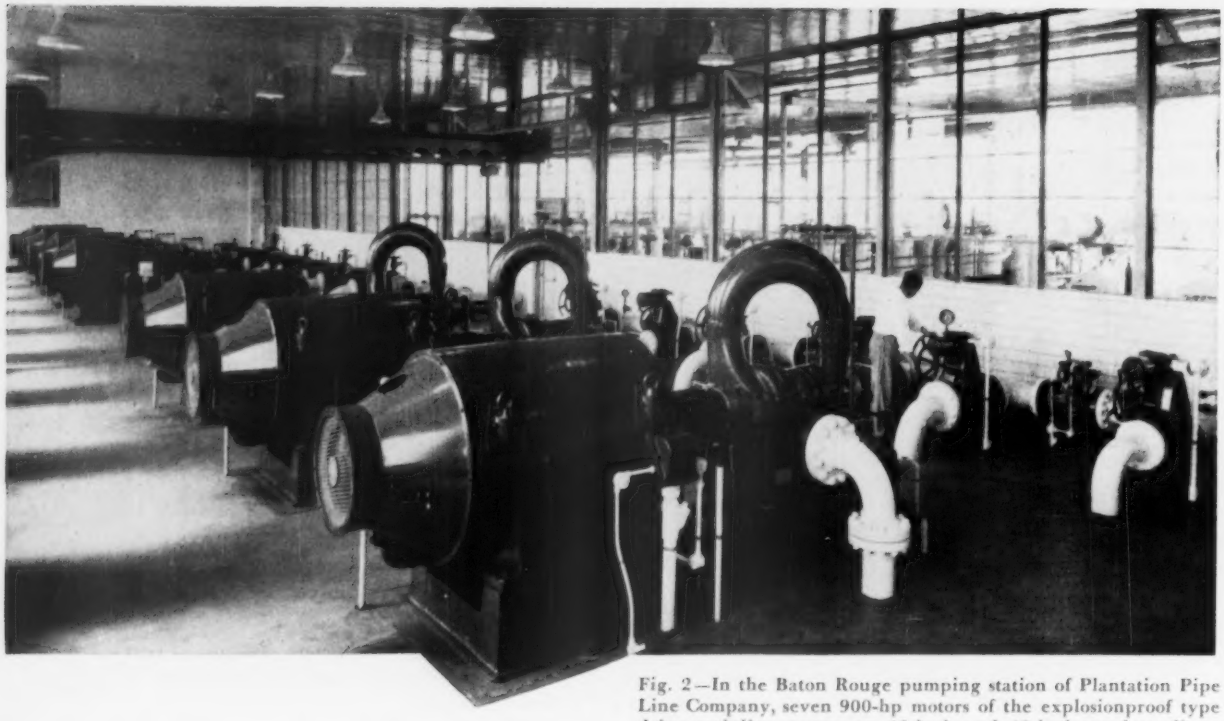


Fig. 2—In the Baton Rouge pumping station of Plantation Pipe Line Company, seven 900-hp motors of the explosionproof type drive mainline pumps on 12-inch and 18-inch products lines.

type is relatively new to long-distance natural-gas transmission pipeline operations, and Texas Eastern was a pioneer in adapting it for high-pressure large-diameter lines. Its use at first was to some extent motivated by the fact that it permitted the company to utilize a large portion of the facilities, especially electrical, included in the purchase from the government. However, electrically driven centrifugal compressors proved so successful that they were used extensively in a new 30-inch pipeline, which the company placed in operation in August, 1952. This line extends from Kosciusko, Mississippi, through Alabama, Tennessee, Kentucky, and Ohio to Connellsville, Pennsylvania, and on to the Oakford storage pool near Jeannette, Pennsylvania. The 30-inch line joins the 20- and 24-inch lines at Connellsville, Pennsylvania.

With this and other construction, Texas Eastern has grown so that it now operates a system of more than 4200 miles of pipeline with a delivery capacity of more than 1.2 billion cubic feet of gas per day. Of the present 36 compressor stations totaling 357 410 hp, 20 are equipped with single-stage centrifugal compressors, each directly connected to an electric motor, and have a total of 221 250 installed hp. The stations range in size from 3750 to 19 000 hp.

Motors for Main-Line Pumping

Induction motors predominate in present-day installations, due to their simplicity, high efficiency, and good power factor at the speeds of 1800 and 3600 rpm ordinarily required by centrifugal pumps in main-line service.

The induction motor is best adapted to explosionproof construction, a form in increasing demand because it provides the ultimate in safety and self-contained simplicity, with minimum complication of control. Explosionproof motors have risen in available size from 600 hp in 1941 to 3000 hp at 3600 rpm.

Motor ratings for trunk-line stations have frequently exceeded the sizes available in Underwriters' approved explosionproof construction. This has led several large lines to employ totally enclosed force-ventilated motors. Air is delivered to each motor by duct from a separate motor-driven blower and is discharged through a duct to outside atmosphere. The air ducts are usually under the floor for convenience. (See page 151.)

The blower is placed at a safe air source remote from the pump room, usually at second-floor level. Pressurizing the entire system prevents any infiltration of vapors from the pump room. The control system provides an automatic starting sequence in which the ventilating blower starts first, must establish normal air delivery as detected by a flow relay at the discharge end of the duct, and must maintain air flow for a timed purging interval—after which the motor starts. If ventilation should fail while the motor is running the air-flow relay shuts the unit down.

Installations using this ventilation and control system have been in service since 1949 with excellent results. Well over 100 units are in operation or under construction. In large ratings, particularly in units exceeding 1000 hp, their installed costs (including special bedplate, duct-work, blower, blower-motor control, and unit sequence control) are sufficiently below those of explosionproof motors that they predominate in recent installations.

Before development of the explosionproof motor and of suitable ventilation control for the force-ventilated motor, open motors were commonly used with a fire-wall separating the motors from the pump room. This practice is still employed to some extent. It is particularly applicable to stations using reciprocating pumps, where low-speed drive makes the synchronous motor advantageous.

In such motor rooms it is desirable to maintain the air at a slight pressure differential above the pump room, to prevent inseepage of hazardous atmosphere from the pump room. This can be accomplished by delivering into the motor room the required air to maintain acceptable ambient temperature.

and discharging this air through ventilators adjusted for the desired pressure drop. A variation of this arrangement is the self-ventilated motor, which draws air through the motor base from outside the station, passes it through the motor, and discharges into the motor room.

Cases can be cited—many on older crude-oil lines—where open squirrel-cage motors have operated for years right in the pump room. But the urgency of safety and the economics of insurance have led to a much more conservative viewpoint in motor selection for modern stations.

Placing the main pump units outdoors offers advantages immediately apparent, such as saving in building cost and reduction of atmospheric hazard. However, in most localities, shelter is desirable for inspection and maintenance work on pumps as well as on motors in inclement weather; even in dry climates exposure to dust storms has to be considered. Typical of outdoor motor practice are 1500-hp, 3600-rpm weather-proof motors under construction for a large crude-line station in Louisiana.

Where main-line pumps are fed from tanks, booster pumps are installed to insure delivery to the main pumps at positive suction pressure. These boosters, ranging up to 350 hp, are generally outdoor installations. They are frequently of the vertical type with the pump below tank-bottom level, allowing them to "draw down" the tanks completely.

Auxiliaries include motor-operated valves for the main pump units, manifolds, strainers, and scraper traps; also sump pumps and other auxiliary pumps, air compressors, and ventilating fans. These drives are usually below 25 hp and employ explosionproof motors.

Motor Control and Its Coordination with Station Layout

Starters for main pump units generally are not designed for hazardous atmospheres, since the required construction cannot be provided economically in the interrupting ratings necessary at many stations. Furthermore, in large sizes, inspection and maintenance become difficult. For these reasons, as well as for ease of installation and maximum operator safety, the trend in main-unit control is toward conventional metal-enclosed equipment. This apparatus must be situated in a safe area. It can be of outdoor design, or indoor type, either in a separate building beyond the hazardous area or in a control room adjacent the pump room. The latter is accomplished through ventilation whereby the control room is maintained at a pressure slightly above that in the pump room.

Safety Dictates Design of Station Ventilation

Details vary in different installations, but in general the plan is to pressurize continuously the control room with safe air and to exhaust air from the pump room. The two rooms have no communicating openings except separate outside entrances equipped with automatic door closers.

The pump room has duplicate exhaust fans with automatic shutters, the fan rotors being mounted directly on the shafts of explosionproof motors. These motors can be two-speed for seasonal variations in air requirement. Air enters the opposite wall of the pump room through a louvered opening equipped with filters and with a heating coil when required for winter use. In stations employing force-ventilated motors whose loss heat is practically all carried out in the ventilating air stream, the pump-room exhausters need be large enough only for room ventilation. A station using explosionproof motors on the main units must have larger pump-room exhausters to remove the motor-loss heat and maintain a satisfactory ambient temperature in summer; in winter the air flow can be reduced and the motor loss utilized to heat the pump room.

It is important to maintain pressurized ventilation in the control room. Installation of two fans is desirable, one for reserve. In some installations standby power generation insures control-room ventilation during outage of regular power. Interruption of air delivery can be indicated by a flow relay to warn the operator. Some recent stations employ a relay actuated by loss of differential pressure between control room and pump room, with a time delay to cover normal fluctuations. With proper arrangement of control and power-distri-

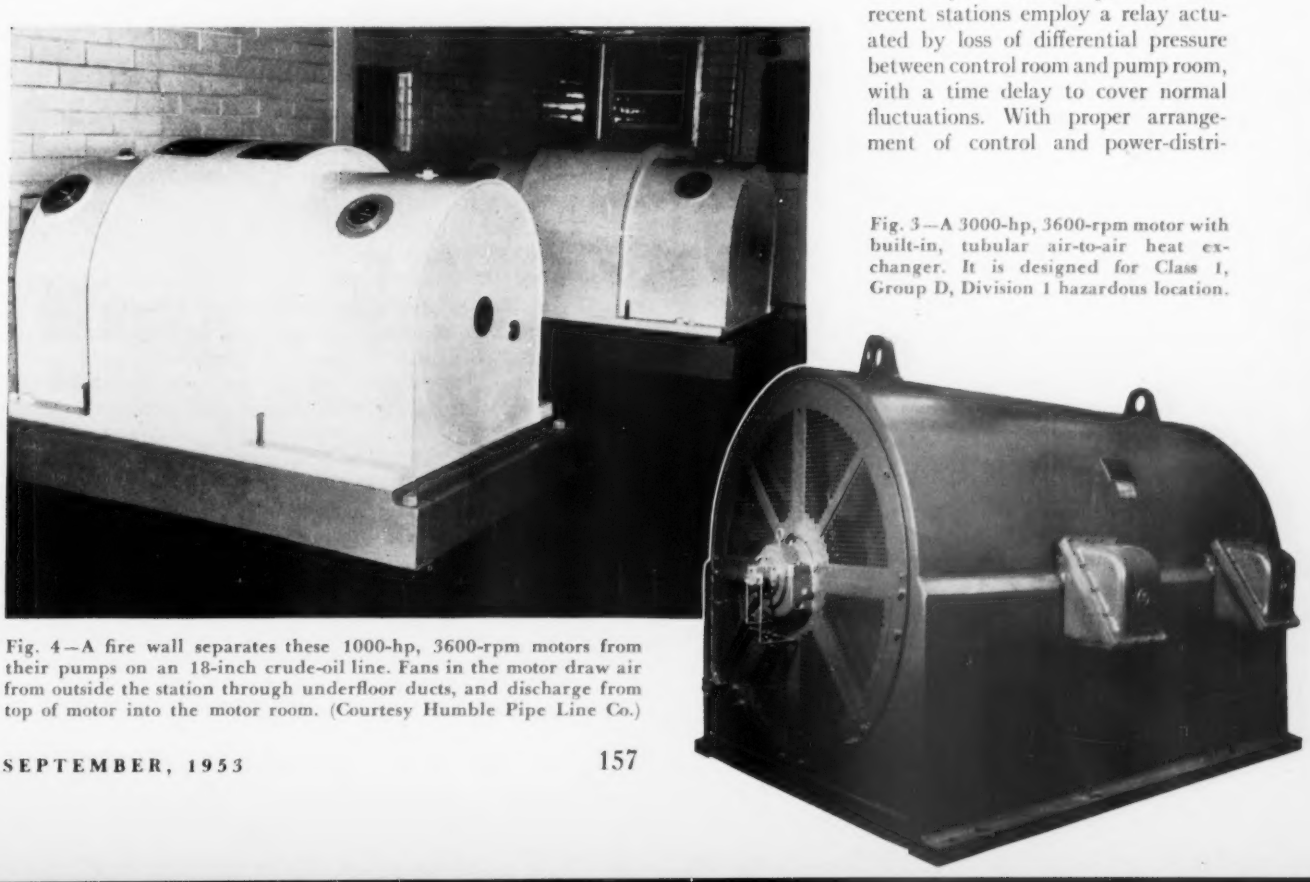


Fig. 3—A 3000-hp, 3600-rpm motor with built-in, tubular air-to-air heat exchanger. It is designed for Class 1, Group D, Division 1 hazardous location.

Fig. 4—A fire wall separates these 1000-hp, 3600-rpm motors from their pumps on an 18-inch crude-oil line. Fans in the motor draw air from outside the station through underfloor ducts, and discharge from top of motor into the motor room. (Courtesy Humble Pipe Line Co.)

bution circuits, this relay can trip the main breaker to de-energize all non-explosionproof control-room equipment in the station.

Problems in the Design of Centralized Control Boards

Modern pipeline stations increasingly employ centralized control systems for manifolds for the main units, and for those auxiliaries directly involved in line operation. In centralized-control systems the sequences incident to starting and stopping the pump units and associated valves are carried out automatically after initiation by pushbuttons, which are grouped on control boards or consoles along with indicating lights and hydraulic instrumentation. The design of operating boards for centralized-control systems involves some important safety considerations.

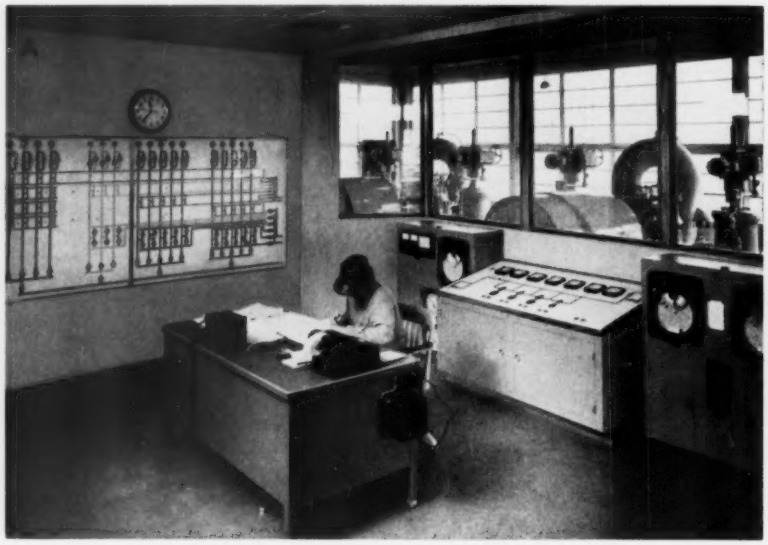
A few boards for this service have been built for location in the pump room, requiring explosionproof electrical devices and wiring. Space limitations present serious difficulties with this type of equipment in any but the simplest installations.

The trend has therefore been toward non-explosionproof construction for placement in control rooms that are maintained non-hazardous by ventilation practices already described. For good visibility of the pumping equipment the control room is usually elevated some 30 inches above the pump room. This also prevents intrusion of liquid into the control room should a break occur in the pump room.

The control board usually comprises an electrical console, and a separate panel or panels for line instrumentation. The latter ordinarily consists of pressure gauges, pressure controllers and recorders, flow recorders, and sometimes indicators of flow, line temperature, and tank level.

Some instruments have pressure elements that are piped directly to the line. As precaution against their failure the panel should provide gas-tight separation of such elements from all electrical devices and circuits, and should be tightly sealed in the wall or window or sash that separates the control room from the pump room. The hydraulic instruments should be mounted on the panel with gaskets, and their cases provided with rupture diaphragms, for spillage through the rear of the panel into the pump room in event of element failure. Some installations are made with velocity-check valves to minimize spillage if an instrument element fails.

Much interest is directed to recent installations of a pressure-measurement system developed by Baldwin-Lima-Hamilton Corporation. It uses an electrical strain-gauge cell as the primary device for actuating pressure indicators and controllers.[2] Each cell is directly tapped to the appropriate point in the station piping, eliminating instrument lines. A conspicuous advantage of this system is the safety that accrues from elimination of fluid-filled lines in the control-board assemblies. Compartmentation problems disappear, and freedom to mount pressure indicators close to other electrical devices has brought about their incorporation into flow-diagram boards with major improvement in readability. The console, above, has seven such pressure indicators.



A—From this panel in the station control room the operator controls the manifold and the tank-farm booster units. The panel diagram corresponds to the actual piping layout, with a different color to indicate each shipper's piping. In the center of each motor-operated valve symbol is a specially designed pushbutton, preset by turning to the *Open* or *Close* position, then pressed momentarily to cause operation. The head is flush in the valve symbol—blue for closed, amber for open—and carries the letter C or O to make doubly sure. The console at right controls three 2000-hp and one 1000-hp main-line pump units and associated valves. *B*—At Colorado City is the initial station of the West Texas Gulf pipeline. The manifold serves the pipeline like a switching yard does a railroad. Interconnections between incoming lines, tank lines, and station piping provide for routing the oil as required by schedules. Motor-operated valves change the flow with precision in response to the push of a button. In foreground is one of 16 in-the-line booster pumps with unitized outdoor control for the 350-hp motor and associated valves. *C*—Outdoor switchgear on a large crude-oil line includes main 4160-volt breaker, tripping battery, and control for essential auxiliaries.

How Electric-Power Distribution Copes with Atmospheric Hazards

Along with problems of equipment design and location, the arrangement of electric circuits is of prime importance to safe station operation. The electric-power company generally delivers energy to the pump station at 2300 or 4160 volts, depending on station size. Commonly, the principal station load is fed through a main breaker. It is advantageous to install this breaker adjacent to the transformer substation, which should be situated at such distance from the pumping station as to be definitely outside the hazardous area.

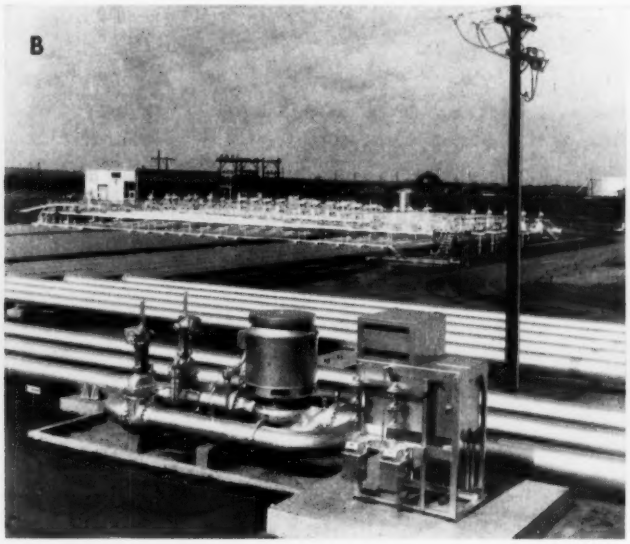
In addition to the usual protective relays, the main breaker is generally arranged for tripping from an emergency button on the control board, and desirably by one or more such buttons outside the station. The indoor switchgear and auxiliary control are thereby isolated from the power supply, except for certain "essential" auxiliaries that remain energized, being fed from the supply side of the main breaker. These essential auxiliaries include the valves that isolate the station from the pipeline, the room ventilating fans, and certain lighting that should always be operable. On all circuits that remain energized after the main breaker is opened, the devices and wiring within the station are explosionproof. Selective pushbutton control is provided both within and outside the station for the room ventilating fans, since it

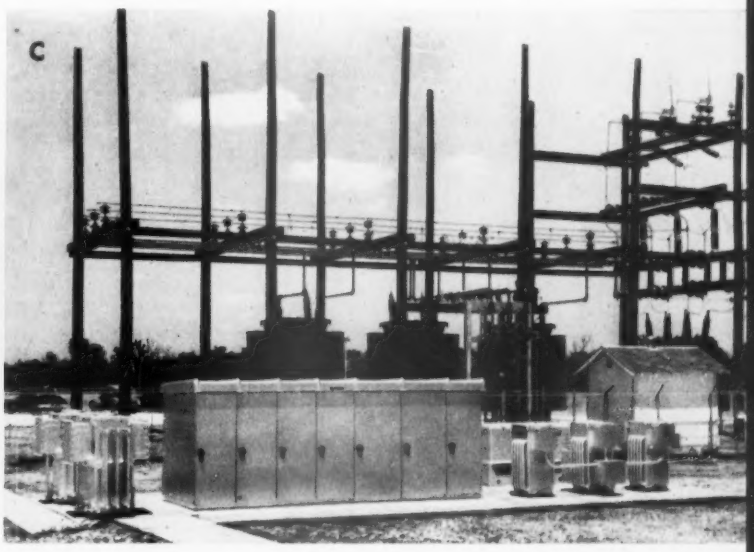
may or may not be desirable to operate them in event of an emergency.

In some recent stations, control for the essential auxiliaries is located near the main breaker, in an outdoor housing, and is arranged for automatic transfer, upon failure of outside power, to an emergency engine-generator set.

Communication circuits can be isolated by carrying these circuits through relays located in the outdoor gear and de-energized by operation of the emergency button. For emergency communication a telephone can be provided at the outdoor switchgear.

Perhaps the safety measures outlined in this discussion seem unduly elaborate. Their practice is backed by experiences—fortunately few—where less extensive precautions have been grimly demonstrated as inadequate.





Remote Control of Pumping Stations

The outstanding success of stations using local centralized sequence control has pointed the way to distant operation. This is accomplished by adding to the local control a pair of master starting and stopping relays that parallel the local unit pushbuttons, and by supplying supervisory control equipment and control channels to operate remotely these relays and indicate the condition of the controlled apparatus. In addition, telemetering equipment is usually employed for transmitting to the controlling point information about the hydraulic conditions at the controlled station.

Unattended stations present additional requirements in equipment protection. One of the more critical problems is that of automatic shutdown on excessive leakage from the pump seals. This is effected by draining the seals of each pump to a small tank having an outlet to the station sump (or equipped with an individual pump) capable of handling only the normal rate of leakage. Excessive leakage raises the liquid level, causing a float switch to initiate the shutdown sequence, including closure of the suction and discharge valves to isolate the unit from the line. The main station sump likewise should be equipped with a high-level shutdown float switch.

If the station has conventional non-explosionproof control equipment in a room maintained non-hazardous by pressurized ventilation, it is important that a cessation of pressure in the control room act to remove the station from the line.

Conservative safety engineering in the design of stations for unattended operation gives preference to location of control equipment remote from the hazardous area, either in an outdoor enclosure or in a separate building.

Microwave Supervisory Control Installation on Plantation System

As this is written, an interesting remote-control installation is nearing completion on the Plantation Pipe Line Company's north branch line from Bremen, Georgia, to Knoxville, Tennessee. Here two new booster stations, Smith and McGaw, will be operated by supervisory control over microwave radio from existing attended stations, Bremen and Jersey, respectively, each about 50 miles upstream. Each station contains a single 600-hp pump unit driven by an explosionproof motor, with control for automatic sequence operation of associated motorized valves and pump-room ventilation.

Microwave—The 2000-megacycle microwave system comprises two terminal stations and five repeaters, covering a distance of 156 pipeline miles, from Bremen to McGaw. Aside from the supervisory control and telemetering channels, party-line telephone communication is provided between the four pumping stations, as well as a service channel with telephone at each radio-equipment location, and alarm and indication at Bremen of faults throughout the microwave system. Antennas for very high frequency (vhf) transmission are installed for future tie-in with mobile radio used in maintenance. Teletype or other service channels can be added.

Each radio location has a 5-kw, 1200-rpm diesel-engine generator unit for standby power service, with automatic starting and transfer control. All standby sets are arranged for remote test-starting from Bremen, weekly, with a minimum run of 20 minutes; this is accomplished over the microwave system, and an indication of the operation is provided at Bremen. The engine is started by a cranking winding on the generator, from a 24-volt, nickel-cadmium battery equipped with trickle charger from the a-c power supply. At two of the repeater stations, where utility power

is not available economically for radio operation, a duplicate engine generator serves as the regular source of power.

Supervisory Control and Telemetering—The supervisory control is centered on a diagram panel at each controlling station. This panel contains three indicators for continuously telemetered pressures—pump suction, pump discharge, and outbound line; also a recorder for telemetered flow.

Instrumentation is actuated by electrical strain-gauge cells. The voltage from each cell-bridge is amplified for actuation of a local pressure indicator, with an intermediate output to the pressure-telemetering transmitter. Flow measurement is by differential pressure across an orifice on the discharge side of the pump, similarly telemetered to a flow recorder at the controlling station. A second flow-measurement cell actuates a local indicating flow controller with high- and low-flow shutdown contacts. This instrument operates, in conjunction with suction and discharge pressure-limit controllers, to position pneumatically a throttling control valve on the discharge side of the pump. The valve is controlled so as to limit the flow through the pump to a normal maximum of 1460 barrels per hour, the pump suction pressure to a minimum of 50 psi, and outbound pressure to 1050 psi.

Electrical instruments at the controlled station indicate supply voltage, incoming line current, and wattage. None of these is telemetered. Local start and stop pushbuttons are provided, as well as a remote-control cutoff switch.

Protective Relaying—Local protective relaying is provided to trip the main breaker in case of single-phase, reverse-phase, and abnormal voltage, with automatic reclosure when conditions are normal. Overcurrent trips the main breaker with lockout, requiring local reset before reclosure.

Automatic shutdown of the main pump motor occurs on low suction pressure, high suction pressure, high line pressure, and opening of main breaker, after which the unit can be restarted remotely when conditions are restored to normal. Automatic shutdown and restarting of the main pump unit occurs on passage of a line scraper. Automatic shutdown with lockout requiring local reset occurs on: pump-room ventilation failure, instrument-air failure, battery undervoltage, pump-motor overcurrent, locked-rotor or prolonged starting current, incomplete starting sequence, overtemperature of motor, bearing, or pump case, high or low flow, pump-seal leakage, high level of sump, and excessive pump vibration.

Vibration Relay—A new development for protection of centrifugal pumps in event of "roughness," this device should prove an important contribution to the safe operation of stations unattended. It consists of an acceleration mechanism responding to vibration at the frequency of the pump speed to close a tripping contact when a predetermined amplitude is reached. The mechanism is pivotless and free of wearing parts. It is enclosed in an explosionproof housing mounted rigidly on the pump case.

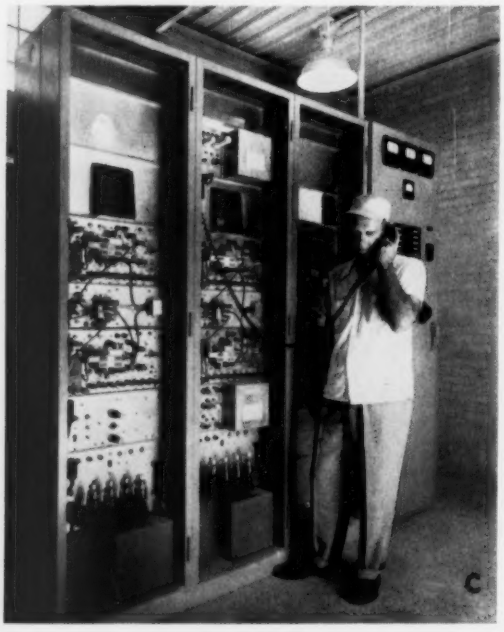
A—Color photo shows a microwave repeater on Horseleg Mountain.

B—Supervisory-control panel installed in the Bremen Station.

C—Microwave equipment at the Smith Station (cabinet doors off).

D—Supervisory-control telemetering and switchgear equipment at Smith Station, as now in operation.

E—Pumping station on a major system transporting refined products. Here, from 31 tanks, totaling over one million barrels' capacity, shipments are pumped into pipelines in endless succession of batches for underground trips to delivery terminals hundreds of miles away. This station serves two main pipe lines and two branch lines.



Pig Detector—Another innovation in the Plantation project is the use at each remotely controlled station, of two inductor-type detectors to signal the approach and departure of a line scraper, commonly called "pig." To prevent the pig from lodging at the point where the station suction piping takes off from the main line, the incoming detector, installed upstream from this point, shuts down the station as the pig passes. The pig then proceeds straight ahead, through a full-opening by-pass check valve, and through the outgoing detector, which then restarts the station, restoring normal operation. All this is accomplished without attention by the operator at the controlling station, except that he receives audible and visual signals of the event. The scraper-passage detector operates electromagnetically at ordinary voltage and frequency and without any device protruding into the pipe.

Operation—Procedures at the controlling station are simplified to the utmost by using a diagram panel similar to these from which the attended stations are operated. Remote starting and stopping are accomplished by pushbuttons.

The supervisory control operates by transmitting codes of impulses between the controlling station and the controlled station.[4] Each signal consists of a group of impulses varied to transmit the desired intelligence. The two sets of supervisory control equipment (Bremen-Smith and Jersey-McGaw) each utilize one microwave channel, failure of which results in automatic transfer to a spare channel.

Indicating lights are provided for channel supervision, indication of point-selection, supervision of scraper passage and of protective relaying, and position indication for main breaker, motor starter, and suction and discharge valves.

On all trouble-supervision points and the scraper supervision point, an audible alarm accompanies the red-lamp indication. The alarm is silenced when the reset button is pushed. All trouble-lamp indications are maintained until the reset button is pressed and the trouble is cleared. The use of maintained lamp indications eliminates the flashing of lights employed in conventional supervisory control to indicate operations initiated at the controlled station.

In this "Visicode-P" (pipeline version of supervisory control) no alarm or attention-getting indication is produced when a premeditated change occurs, such as the transition of a valve from one position to the other in a sequence-control system. This transition is accompanied only by the appropriate changes in light indication.

In case of trouble at the controlled station, all necessary information must be transmitted to the controlling end to permit dispatching of the right maintenance personnel. To accomplish this with minimum supervision points, several protective functions are grouped under common indications on the controlling panel. Thus, "Power Failure" includes single phase, reverse phase, and undervoltage. "Electrical" includes winding overtemperature, running overcurrent, starting overcurrent, short circuit, and incomplete sequence. "Bearing" includes motor bearing over-temperature and pump vibration. "Seal-Sump" includes high pump-seal drainage and high main sump level.

The Plantation microwave-supervisory control system is believed to represent practices that will find wide application in future pipelining. Present microwave systems can provide for simultaneous use as many as 30 voice channels, each capable of sub-multiplexing into as many as 15 channels for telegraphic functions. Supervisory control utilizes a single channel to perform a multiplicity of operations and indications. Telemetering is available, utilizing either the variable frequency or impulse duration principle, and may be continuous or selective, as dictated by considerations of channel economy. These tools and others yet to be developed will be used increasingly to accomplish remote control of pipeline stations not only from neighboring attended stations but directly from system dispatching points.

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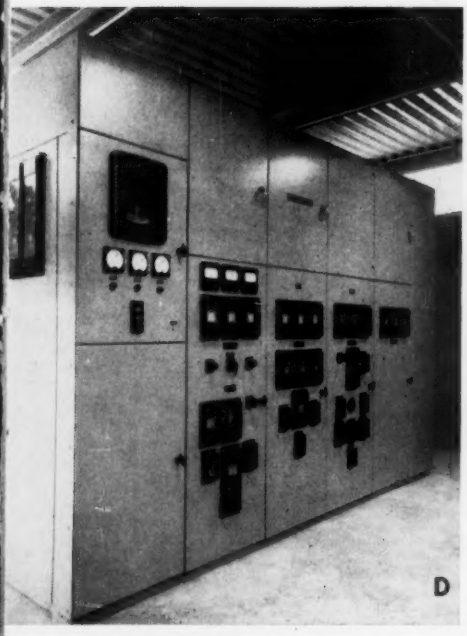


Industrial Regulating Systems

Whenever a machine or production process is automatic to any degree, control problems exist and some regulatory system is necessary. Luckily, the basic solution in one industry often is suitable—with slight refinements—for the next. Thus a few types of regulators serve the requirements of the majority of industrial applications.

M. H. Fisher, *Manager, General Mill Sect., Industry Engineering Dept., Westinghouse Electric Corporation, East Pittsburgh, Pa.*

Better production, in every sense, is probably more directly related to the development of better methods of control than any other factor. Whenever an advantage in cost, quality, or rate of production is realized, chances are that a new or improved control scheme is in some way responsible. In the field of electric-machine drives, it is the electrical regulator that provides the continuing impetus toward ever better, cheaper, more quickly made products.

No regulator need be peculiar to a particular industry, for although the manufacturing processes of two industries may differ radically from each other, often the drive-regulating problems are quite similar. For instance, the regulator for a paper-machine single-motor drive is also used, with slight variations, on the drive of a cellophane-casting machine that extrudes liquid cellulose in sheet form, passes this sheet through a fixing process, and finally winds it on a reel. Similarly, the speed regulator used to control a machine tool might just as well be applied to a supercalender, or to an elevator drive. The field of application is extensive, as Table I indicates even though only the major uses of speed regulators are listed. And the reason for this widespread use is the fact that regulators can control voltage, current, speed, torque, or any quantity that can be translated into an electrical signal.

Essentially three types of regulators are used in industrial regulating systems: (1) rotating; (2) magnetic amplifier; and (3) electronic. Each is gaining a fairly well-defined field of application, although there will always be some overlapping. Power capacity, efficiency, response, maintenance, and cost are major considerations when applying any of the three types, but in some cases characteristics peculiar to a certain process—such as space and weight limitations—may be the deciding factors.

TABLE I—CLASSIFICATIONS OF SPEED REGULATORS

Cueing Signal	Main-Generator Voltage	Motor Counter EMF	Pilot-Generator Voltage	Tachometer Frequency
Approximate Percent Accuracy at Top Speed	±3.0	±1.0	±0.5	±0.1
Typical Drive Applications	Hoists Blooming, slabbing, and plate mills (main and auxiliary drives) Bulk unloaders	Machine tools Elevators Hoists Winders Super calenders Electric shovels Tandem cold-reduction mill High-speed steel-mill reels	Paper-making machines Wind tunnels Dynamometers Rubber and plastic calenders Cellophane and runner extruders Tire-testing machines Rod and merchant mills Flying shears Slitting lines	Paper-making machines Man-made fibre spinning machines

Speed Regulators

Although regulators can be used to control any of several quantities, such as horsepower, tension, and torque, the most common type is the *speed* regulator. Basically, four types of industrial speed regulators are used; a convenient way of clas-

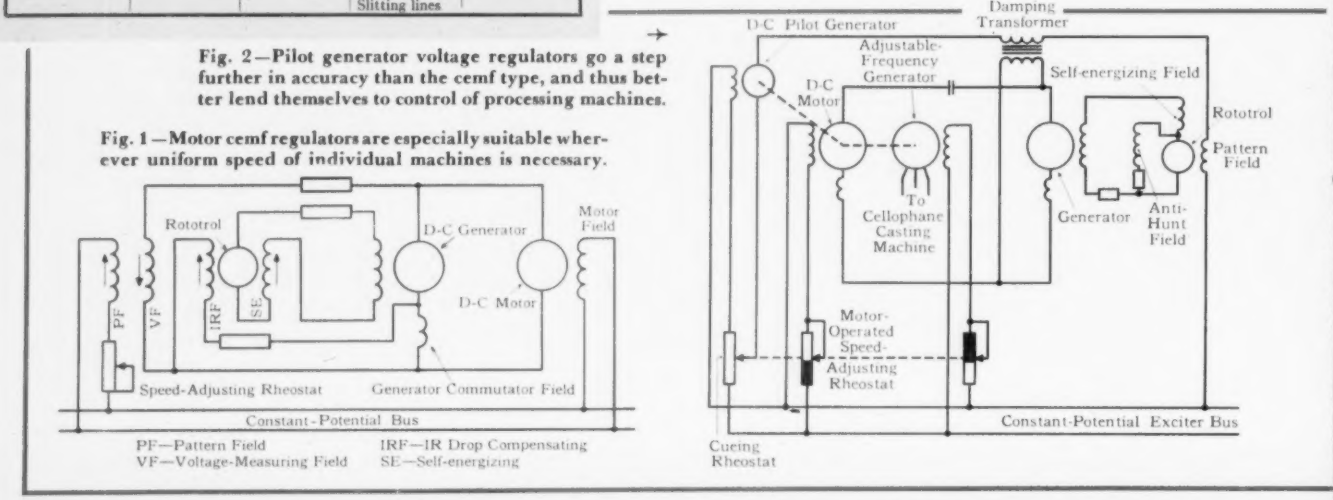


Fig. 2—Pilot generator voltage regulators go a step further in accuracy than the cemf type, and thus better lend themselves to control of processing machines.

Fig. 1—Motor cemf regulators are especially suitable wherever uniform speed of individual machines is necessary.

sifying them is according to approximate accuracy of each and the cueing signal used: ±3 percent—main generator voltage; ±1.0 percent—motor counter-electromotive force; ±0.5 percent—pilot-generator voltage; ±0.1 percent—tachometer frequency.

Ordinary main-generator voltage regulators, as such, are elementary and need not be discussed. However, these regulators used in such a manner as to achieve power amplification of the cueing signal, thus allowing use of a small controller, are fairly complex. The order of this complexity increases when these regulators are used in conjunction with a current-limit over-ride scheme. Because of the additional design considerations these factors introduce in the main-generator voltage-regulator picture, a discussion of this regulator more naturally follows the motor counter-emf and pilot-generator voltage types.

Motor Counter-Emf Regulators

In every case, the selection of a speed regulator depends, ultimately, upon the required accuracy and the nature of the process. For example, a metal planer needs a regulator that will make sure that the cutting speed is maintained within ±1.0 percent. A counter-emf speed regulator is suitable.

Because the speed of the d-c motor is proportional to the counter-emf of the motor, when the field strength is held constant, the speed can be measured by use of armature-voltage and current signals. When the generator voltage is compared —in the regulator—to the sum of a pattern (reference) signal and the IR drop in the motor-generator armature loop, the motor speed can be maintained accurately regardless of load variation. Although Fig. 1 shows use of a Rototrol rotating regulator, it is possible to obtain equally successful results with a magnetic-amplifier counter-emf regulator.

Pilot-Generator Regulators

Many continuous processes, such as manufacture of cellophane, paper and rubber products, require a more accurate regulator that is capable of holding constant speed over long periods to insure minimum variation in quality. Also, speed must be maintained uniform during load changes.

A regulating scheme consisting of a pilot-generator feedback circuit and a Rototrol or magnetic-amplifier regulator provides an accuracy of ±0.5 percent at top speed when the entire speed range is obtained by voltage control (Fig. 2).

This system maintains a constant-speed accuracy over the operating range because it is sensitive to a fixed change in pilot-generator output voltage. This output voltage is proportional to speed. Thus, if the regulator is sensitive to a 0.25-volt change, which, in turn, is proportional to a 4-rpm change, then the regulator holds ±4 rpm over the operating speed range.

To minimize speed changes over a long operation period (24 hours or more), special provision must be made to reduce the effects of ambient temperature variation and exciter voltage variation. The speed regulator for a cellophane casting machine uses a self-compensating pilot-generator circuit to minimize these effects. The generator itself is a special machine that has restricted armature end play, and special frame and pole steel to reduce hysteresis and residual-magnetism effects. And it is operated on the straight part of its saturation curve so that its output voltage changes in exact proportion and direction as does its field current. Its field is in series with the speed-control rheostat so that changes in excitation affect the cue voltage across the rheostat and the output of the pilot generator by proportional amounts. Thus, the circuit is self-compensating and assures constant speed control over long periods.

Speed-regulating requirements of a tire- and brake-testing machine require the use of a special speed regulator similar to that used for cellophane manufacture except for further refinements. Manufacturers must test their tires and brake linings under controlled conditions similar to those encountered in actual operation to be sure that the tires meet specifications. The roadwheel, a large steel flywheel with detachable endplates to allow inertia variation, is used as a moving surface and the tire is mounted on a stationary support. Three types of tests are conducted, depending on the use of the tire and the type of vehicle: (1) in the case of airplanes, the tire is landed on the roadwheel with a force proportional to the weight of the airplane, and the stored energy in the flywheel

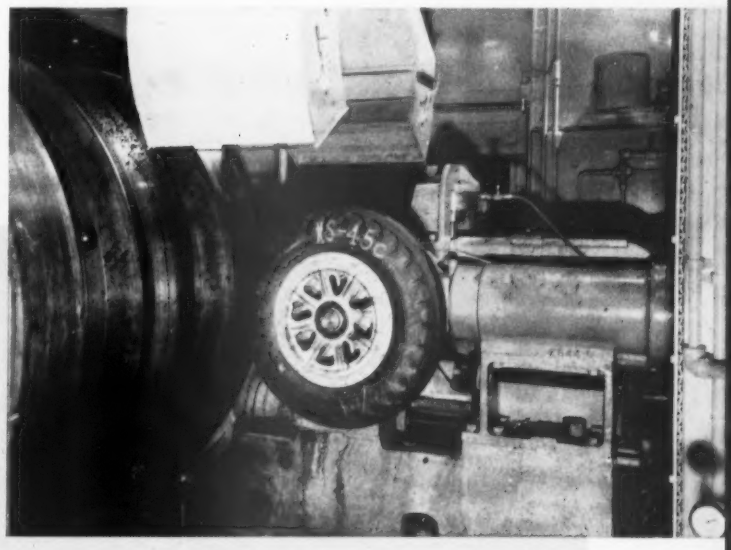


Fig. 3(a)—A tire- and brake-testing arrangement.

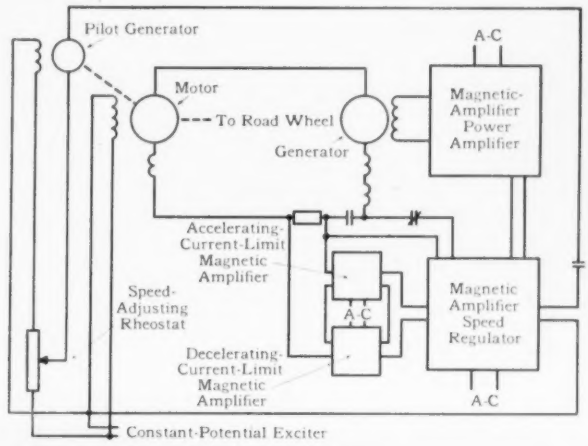


Fig. 3—Special requirements often demand refinements of basic regulating systems, as is the case for this cemf regulator circuit for use with tire- and brake-testing machines.

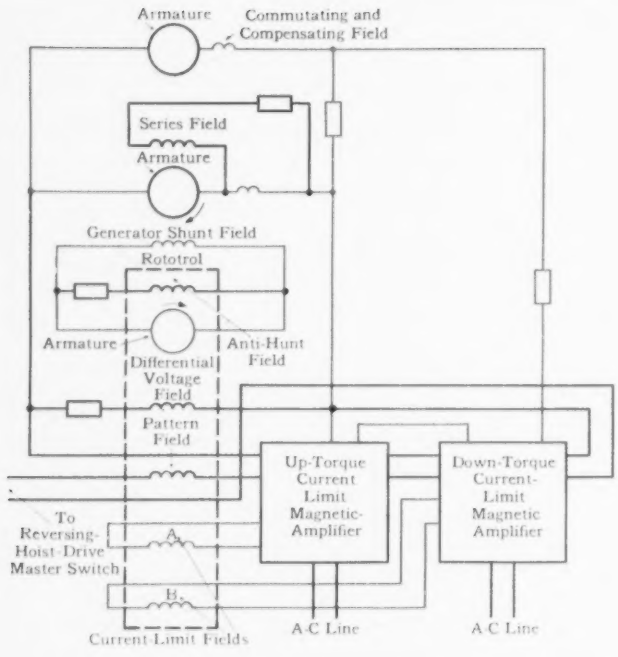


Fig. 4—Magnetic amplifiers provide nearly vertical current-limit cut-off for this speed regulator for a high-inertia-load hoist; thus overloading of mechanical and electrical parts of the drive is avoided.

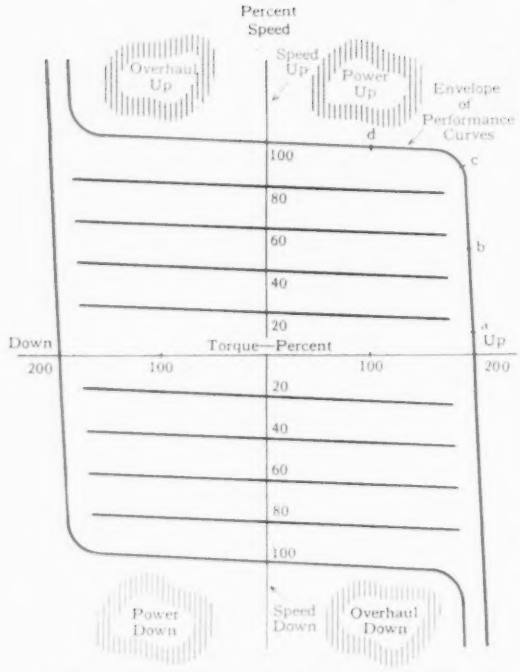


Fig. 5—The use of current-limit magnetic amplifiers limits the amount of torque available during speed-up or speed-down of a hoist, and thus prevents overloading.

is adjusted to be comparable to what the airplane would have; (2) in the case of all vehicles, road testing is done at a fixed speed with the tire running on the roadwheel and pressure against the roadwheel proportional to the vehicle weight; and (3) brake testing is accomplished by pressing the tire against the roadwheel and applying the braking effort, with the stored energy adjusted to be comparable to that of the particular car or airplane.

These tests lead to special control features:

1—The speed-adjusting rheostat is arranged for manual operation, and since the roadwheel has large inertia (1 250 000 lb-ft squared), current-limit protection is provided to safeguard the electrical equipment.

2—Certain tests demand the roadwheel be accelerated to peripheral speeds of up to 250 miles per hour. The tire is landed on the wheel and the speed of the wheel is rapidly reduced by use of brakes on the wheel to simulate an airplane landing. Since the most severe conditions are encountered at the higher speed (stored energy varies as the speed squared), the tests seldom require complete deceleration to stop. To save time, deceleration is often stopped at one-quarter speed (stored energy one-sixteenth of maximum), and the wheel is brought up to top speed again. During deceleration the power is off and the main line contactor is open. Since the main line contactor is closed before the drive comes to a complete stop, the generator voltage must equal that on the terminals of the motor, which is acting like a generator at no load with output voltage proportional to speed (Fig. 3). This is accomplished by feeding the voltage across the main line contactor into the magnetic-amplifier regulator, which maintains the generator voltage at a safe value for contactor closing.

3—Prolonged road tests are conducted at low speed to simulate operation of tractors and very heavy military vehicles. With these tests, speed regulation at values as low as four percent of top speed are provided by the speed regulator at 100-percent load or less.

Main-Generator Voltage Regulators with Current Limit

A high-inertia load controlled by a speed regulator often also requires current-limit protection to avoid overloading both the electrical and the mechanical parts of the drive. Application of such control to an ordinary crane hoist is typical, although it can be applied with equal success to the hold, close, and trolley functions of an ore-handling tower drive, a vertical-lift bridge, paper winder, or other drive having similar characteristics.

When the drive does not require reversible control, a magnetic-amplifier regulator can be used to furnish excitation to the d-c generator. But, when dealing with a reversible drive that requires sizable excitation for its generator, a Rototrol regulator lends itself to the reversing requirement without sacrifice in efficiency or performance. For example, if a magnetic-amplifier regulator were used to supply the generator field for reversing service, either two sets of generator fields (each good for 100 percent excitation) or a reversing magnetic-amplifier scheme would be necessary. The first method is prohibitive due to extra cost for a special generator. The second method results in a regulator that has reduced efficiency at

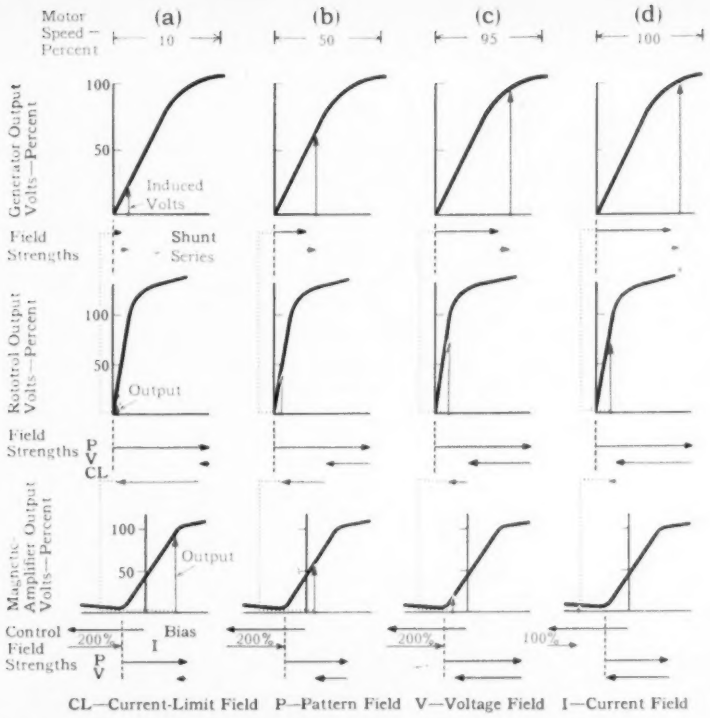


Fig. 6—Imagine that the operator moves the master switch of a hoist from *off* to *full-speed* position as quickly as possible. Further imagine that oscillographic records are obtained at four different motor speeds (a, b, c, d) of all the control fields and outputs of the magnetic amplifiers and the Rototrol, plus the field and output of the main generator. Above are the results of that action.

maximum output. This is in contrast to a Rototrol regulator that is equally efficient at maximum output in either forward or reverse directions. Thus, for reversible control applications, the Rototrol regulator has the edge.

A hoist drive does not require extremely accurate speed regulation, so an ordinary Rototrol voltage regulator is used to obtain reasonable speed-load characteristics. (If more accurate speed regulation is required, a counter-emf speed-regulating Rototrol can be used.) The Rototrol voltage regulator is provided with a pattern field—adjusted by the operator according to the master-switch position—and a differential-voltage field that reflects the generator voltage. These two fields furnish the voltage-regulation intelligence to the Rototrol. Two additional Rototrol fields provide current-limit over-ride for both acceleration and deceleration of the drive. Each field is excited from a current-limit magnetic amplifier. (Since the fields require less than 50 watts excitation, the use of two small magnetic amplifiers—one for acceleration, the other for deceleration—adds little in overall cost or power considerations.)

The current-limit magnetic amplifiers and some unique circuitry are used to give nearly vertical current-limit cut-off. Pattern, voltage, bias, and current fields combined with inherent characteristics of the magnetic amplifier provide the sharp current-limit cut-off performance. The relationship of the various field strengths during acceleration, when the master switch is quickly moved to the full-speed-up position, is shown by Figs. 4, 5, and 6. Acceleration to less than full speed is accomplished in the same manner, but in this case the pattern-field vector would be of less magnitude and the output of the various units would not exceed approximately one half of that shown.

On deceleration to stop, the pattern-field component in both the Rototrol and the magnetic amplifiers is decreased to zero. The voltage field remains in the same direction. But since the load is overhauling in the case of a hoist, the current does not reverse, and the up-torque magnetic amplifier is used to cause a deceleration to stop. The more usual case is that of stopping of an inertia load, such as that of a crane trolley or other mass, where the current field reverses, and the output of the down-torque current-limit magnetic amplifier and the Rototrol allows the deceleration to be accomplished at the set current-limit value. The same two magnetic amplifiers are used to provide protection in both directions of operation, in this case, because the total amount of power used in the circuit is small.

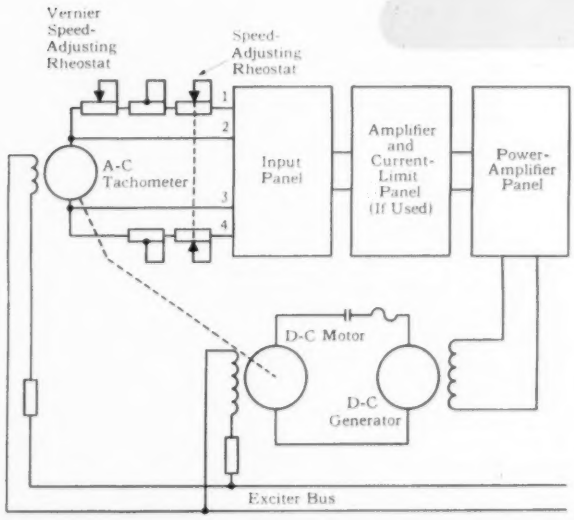


Fig. 7

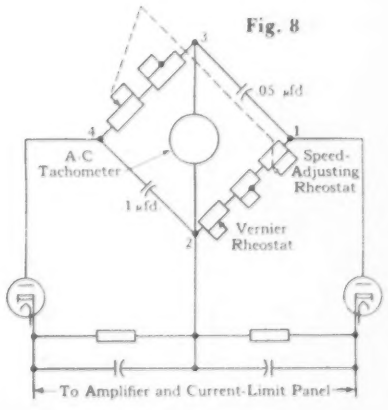


Fig. 8

Figs. 7 and 8—Extremely accurate speed control can be obtained by use of a tachometer frequency regulator. This circuit is used with drives for man-made fiber-spinning processes.

Tachometer Frequency Regulators

When extremely accurate speed regulation is required, such as for a paper-manufacturing or man-made fiber process, an electronic regulator is used to maintain speed according to a measured frequency. In such a system an a-c tachometer is coupled to the shaft of the motor to be regulated (Fig. 7). This tachometer is the inductor type, having both the d-c excitation winding and the a-c armature winding in the stationary member. The motor has 120 teeth-like poles that cause the tachometer to generate a frequency of one cycle per second per rpm or 1200 cycles per second at 1200 rpm.

The output signal of the tachometer is fed into the input section of the electronic frequency regulator, which delivers this signal into a precision resistance-capacitance bridge whose balance frequency is determined by the setting of a rheostat plate in two legs of the bridge (Figs. 7 and 8). The output of the frequency bridge is rectified and applied to the input of the voltage amplifier as a d-c signal voltage. When the bridge is balanced at a frequency determined by the setting of the speed-control rheostat, no signal voltage is applied to the amplifier. If the frequency of the a-c tachometer generator departs from the set value, the frequency bridge becomes unbalanced and applies a signal voltage to the amplifier. The polarity of this voltage depends on whether the frequency is greater or less than the balanced value.

The amplified signal voltage applied to the control bridge of the thyratron rectifiers on the power-amplifier panel determines the amount of voltage applied to the d-c generator shunt field. Polarities are adjusted so that when the a-c generator frequency is too low, the voltage applied to the d-c generator field is increased. This increase in generator voltage speeds up the d-c drive motor and raises the frequency of the a-c tachometer generator to the desired value. Reverse action occurs when the d-c motor speed is too high.

To stabilize the regulated system, anti-hunt circuits are provided. The regulator responds to the rate of change of generator terminal volts so as to oppose variation caused by the change in speed of the pilot generator. Acceleration and slowdown are controlled either by a motor-operated rheostat or current limit over-ride in the amplifier panel.

Constant-Horsepower Reel Drives

In processing industries such as paper, printing, plastics, textile, and steel, material is often unwound from a reel, passed through one or more sections of the processing machine and finally rewound on a reel or beam. Typical of the drives for these processes is the slasher drive in the textile industry (Figs. 9 and 10). The slasher is used to apply sizing to the warp yarn before it goes to the loom to be woven into cloth. In the slasher, yarn is removed from several warper beams assembled in the creel. From the creel the many "ends" or strands of yarn are passed through a sizing solution, then through squeeze rolls to remove some of the solution. The yarn wet with sizing is then dried, separated, passed over a cloth-coated delivery roll, ultimately wound on a core-driven loom beam. In the typical multi-motor slasher drive, two motors carry the yarn through the machine, and a third winds the yarn on a beam preparatory to weaving cloth in the loom.

The beam-drive motor should be capable of operating over

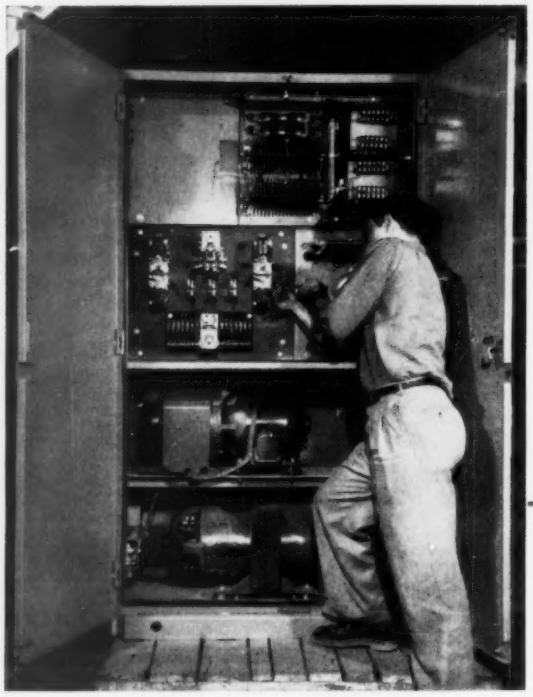
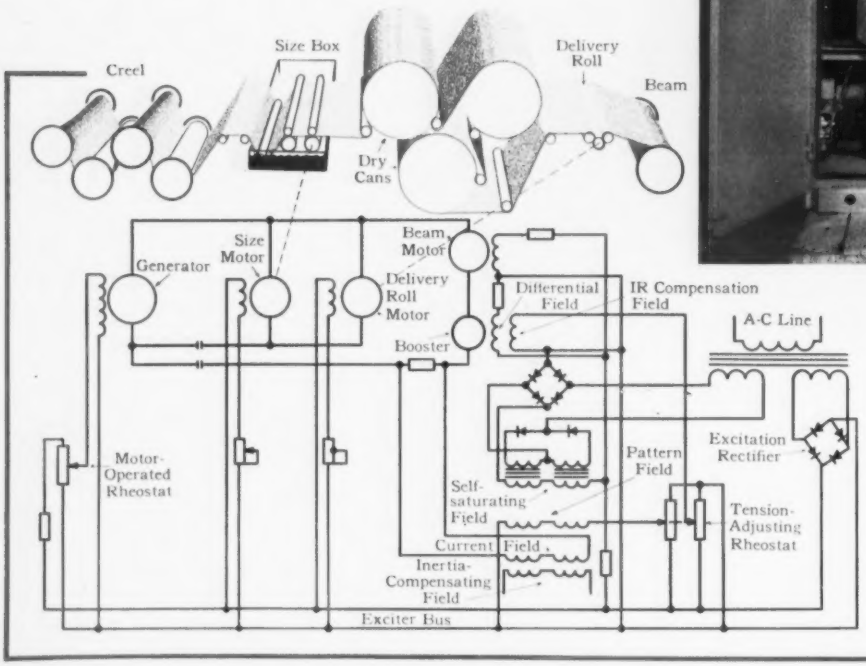


Fig. 10—A package magnetic-amplifier multi-motor slasher drive.



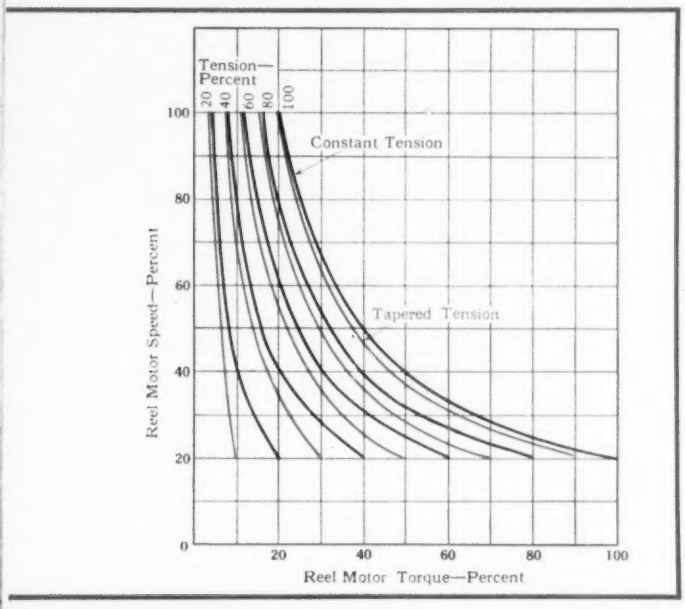
Figs. 9 and 11—A textile slasher machine (left) applies sizing (starch) to yarn preparatory to weaving. Tension is the main problem in this process because it must be uniform over a five-to-one reel-diameter change. Tapered tension (curves at right) tends to reduce the number of strands pulled below preceding layers as the beam builds up.

approximately a five-to-one beam-diameter change and from a 5 to 100 yards-per-minute yarn speed. Since the warp yarn is wound thread upon thread, tension must be held correctly to prevent the oncoming yarn from being pulled down between the outer layers of previously wound yarn. Thus, constant or slightly tapered tension on the yarn being wound is desirable (Fig. 11). Tapered tension makes the core wrap tighter than succeeding wraps, so tends to reduce the number of strands pulled beneath the outer layers of the yarn.

The slasher drive uses a d-c system to achieve the smooth acceleration and deceleration that are required to operate over an adjustable-speed range according to the type and size of yarn being processed. Stabilized shunt-wound d-c motors are used to drive the size rolls and delivery roll, and an adjustable-speed motor is provided to hold tension at the beam. Tension in the beam is regulated over a five-to-one reel-diameter range by a magnetic amplifier and a booster generator. The magnetic amplifier regulates current in the beam motor armature circuit by controlling its field. This results in essentially constant tension at the beam regardless of the beam diameter. Also, by providing an auxiliary field on the IR-drop compensating booster, the magnetic-amplifier current regulator can furnish excitation to the booster in a direction to reduce the motor terminal volts as the beam builds up. Thus, the feature of tapered tension can be accomplished.

These regulators indicate the varying degrees of complexity and accuracy of applications. The more accurate regulator is usually the more complicated, and more expensive from a first cost and maintenance standpoint. Because of this, a study of each regulating problem should be made before the regulator is selected, and the simplest regulator that will do the job adequately should be used. A precision regulator should be applied only when a precision job is required.

This is the concluding article in a series highlighting the various problems of industrial regulating systems. Others—and the issue in which they appear—are:
November, 1952:
"Industrial Applications of Feedback Control Systems," by R. W. Moore
"Industrial Regulators—The Role of The Anacom," by J. T. Carleton
"Regulating Systems for the Steel Industry," by W. R. Harris.
March, 1953:
"Paper Mill Controls—Fast, Precise, Dependable," by M. H. Fisher
July, 1953:
"Regulators for the Marine Industry," by S. A. Haverstick



New Applications for *Thermalastic Insulation*

When a vastly superior material is developed for one application, the engineer's immediate reaction is to look for other uses. Such has been the case with Thermalastic insulation. Since its initial use on high-voltage turbine generators, it has been adapted to waterwheel generators and large motors, with significant improvements.

THERMALASTIC insulation was first applied to high-voltage turbine-generator windings in 1949, and became the Westinghouse standard for this use in 1950.* Even while the first Thermalastic-insulated coils were being wound, work was under way to extend its application to other electrical machinery, where the manufacturing problems were considerably different. This development has been completed, and the superior insulating characteristics of Thermalastic have been extended to waterwheel generators and synchronous condensers, and now to large a-c motors. And while this development was being done, Thermalastic was used successfully in turbine generators with a combined rating of some six million kilowatts.

Thermalastic is basically a mica insulation. Large mica splittings are bonded into either a tape or a wrapper, depending on the size and shape of the coil to be wound, with a strong, resilient synthetic resin. The wound coil is vacuum impregnated with a heat-reactive, solventless resin, and then cured in an oven.

This insulation is used as the major ground wall on both class A and class B coils. Class A coils also employ organic materials. The class B coils use mica and glass as turn, strand, and ground insulation, and outer binder tapes.

Special Characteristics of Thermalastic Insulation

Because of the materials used and their method of application, Thermalastic insulation has many advantages over conventional types:

1—The dielectric breakdown strength per unit thickness is increased at least 20 percent.

2—The voids between the mica splittings are completely filled with the resin impregnant and there are no internal voids to ionize. The voltage endurance (time to failure at a fixed voltage) is increased by a factor of more than ten.

3—The resilient nature of the resin impregnant makes Thermalastic an elastic insulating material. Differential expansion

Prepared jointly by Graham Lee Moses, Manager, Development Insulation Section; William Schneider, Manager, Commercial Insulation Section; E. C. Whitney, Manager, Salient Pole Section; and M. R. Lory, Manager, Motor Section; all of the Generator Engineering Department, Westinghouse Electric Corporation, East Pittsburgh, Pa.

*"Thermalastic Insulation Improves High-Voltage Generator Coils," by Graham Lee Moses. Westinghouse Engineer, July, 1950, p. 163.

of copper, iron, and insulation during cyclic heating thus does not result in rupture or permanent displacement of the mica.

4—The insulation power factor is decreased by one half to two thirds. The power factor versus voltage curve is also somewhat flatter.

5—Tensile strength is more than thirty times that of conventional insulation.

6—The resin impregnant is thermosetting, and does not melt once it is polymerized. This eliminates run-out even at severe overloads.

7—The moisture resistance of the resin impregnant itself and the high degree of fill achieved in the impregnating process make the windings highly resistant to moisture.

8—The chemical inertness of the resin impregnant makes the insulation resistant to attack by ordinary solvents, lubricating oils, and weak acids or alkalies encountered in most industrial service.

9—The solidity and density of Thermalastic insulation render it impervious to contamination from many agents encountered in industrial service.

10—The complete chemical reaction of the resin during processing, and the high thermal endurance of the cured impregnant assure long life for coils.

Waterwheel Generators and Synchronous Condensers

Thermalastic was initially developed for large, high-voltage turbine generators that utilize half-coil construction; it was not immediately applicable to waterwheel generators and synchronous condensers. These machines are normally wound with full coils, which require considerable distortion during winding, and it was necessary to study the actual deformations, and set limits on the maximum possible distortion.

Thermalastic insulation has great tensile strength and rigidity as compared to the plastic asphalt-bonded insulation formerly used, because it is thermoset and hence does not have the plastic flow of its predecessor. In other words, full-coil distortion was not a great problem before, because the plastic flow of asphalt bond permitted deformations far beyond the elastic limit. But in the case of Thermalastic, there is no plastic flow, and all deformations must be held within the elastic limit of the composite insulation.

Several new tools and fixtures were developed, and a number of experimental full coils were made and wound in a waterwheel generator. After the coils were wound in place, a throw (group of coils) was lifted (removed) to make certain coil replacement would be possible. The throw was then closed again, and finally all coils were removed and thoroughly inspected and tested.

The successful completion of this phase of the development led logically to the winding of a complete stator. A 29 000-kva waterwheel generator that had been in service for a considerable number of years at the Jordan Dam of the Alabama Power Company was scheduled for rewinding, and it was decided to use Thermalastic insulation. The stator, consisting of 486 coils, was rewound in February, 1952 (Fig. 1). No difficulties were experienced, and all coils passed overpotential tests.

Thermalastic insulation has continued to be used in winding large waterwheel generators and synchronous condensers, and new production facilities for high-voltage full coils are in operation. Not only will all new machines of these types be wound with Thermalastic insulation, but the rewinding of machines now in service will further extend its advantages, in some cases making it possible to increase ratings or lower operating temperatures by increasing the copper conductor cross-sectional area.

Thermalastic for Large A-C Motors

The success of Thermalastic insulation on large high-voltage turbine generators, and its application to large waterwheel generators and synchronous condensers, has brought

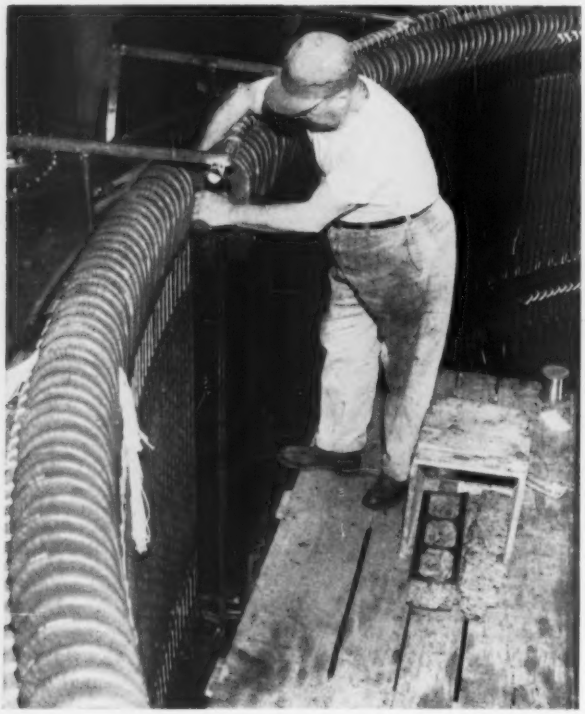


Fig. 1 (left)—Rewinding a 29 000-kva waterwheel generator with Thermalastic. Fig. 2 (above)—A spray test of an induction motor.

Table I—Physical Properties of High-Voltage Generator Insulation

	Tensile Strength	
Room Temperature	Asphalt-Bonded	Thermalastic
100°C	2000 psi 90 psi	6600 psi 2800 psi
Coefficient of Expansion per Degree Centigrade		
	Asphalt-Bonded	Thermalastic
Thickness	300×10^{-6}	72×10^{-6}
Length	6.85×10^{-6}	6.66×10^{-6}

about an extension of its advantages to large a-c motors. The particular form of Thermalastic insulation that was first developed for high-voltage turbine-generator windings was well adapted to those windings, but experience showed that this identical insulation was not especially suited for application to smaller and lower voltage coils and windings. Some modifications had to be made in the resin impregnant to facilitate handling, and new high-speed processing techniques had to be developed to permit economical production. These manufacturing problems have been solved, and the application of Thermalastic insulation to low-voltage coils is now an economic reality. The same advantages achieved in the high-voltage generators are now obtainable on large motors.

A test of the resistance to moisture of Thermalastic insulation is shown in Fig. 2. This is an open-type, 950-hp, 4160-volt, squirrel-cage motor running at normal voltage while water is sprayed into the inlet openings. Immediately following the spraying, the coils successfully withstood 1.7 times the normal line-to-line voltage applied between the winding and the core. This is three times the normal line-to-ground operating voltage.

A more informative test of the resistance to moisture of Thermalastic insulation is shown in Fig. 3. The stator of a 950-hp, 4160-volt motor was mounted vertically with a standpipe through its center. The standpipe was equipped with nozzles that sprayed all parts of the winding with water. Over 200 000 gallons of water were sprayed over the winding during the 275-hour test. For comparison, a standard class B winding was also tested in the same manner; the results of both tests are shown in Fig. 4. The insulation resistance of the Thermalastic winding flattened out at one megohm, where the standard winding was only one third as good. The superiority of Thermalastic insulation is best shown in the recovery curves after the water was shut off. The windings were not dried, but were left in place at room temperature. During the first part of the recovery cycle there were puddles of water under the motor from the spray. In spite of these conditions, the insulation resistance of the Thermalastic winding recovered to ten megohms in one hour. This rapid recovery showed that the moisture was all on the surface and had not penetrated into the insulation. In contrast, the standard insulation required 40 hours to recover to ten megohms, and the much slower rate of recovery showed that the moisture had penetrated into the inside of the insulation walls.

Application of Low-Voltage Thermalastic Insulation

The principal advantage of Thermalastic insulation for motor windings is its superior resistance to moisture, dirt, oil, acid, and alkalies. The reason for the superior performance is that the impregnating resin is very stable chemically, and, as mentioned, contaminating substances cannot enter.

Thermalastic insulation has been used on weather-protected motors for outdoor service for approximately one and one half years. It has been used for the same period on motors in rubber mills, which are subjected to a lamp-black contamination, and in other applications where the operating conditions were extremely severe. These included chemical plants and some steel-mill drives with the motor located out in the mill. It has been applied in all of the most severe locations where standard motors were not giving satisfactory service. No field failures have occurred on any motor in service with Thermalastic insulation. The performance and reliability of motors with the new insulation under adverse operating conditions should far exceed anything attained with previous types.

Facilities for the manufacture of this insulation are being expanded as rapidly as possible. At present, not all machines can be built with Thermalastic, and its use is restricted to the severe applications where it is most needed. It is expected that it will be applied to all large motors, of approximately 500 hp and above, in the near future.

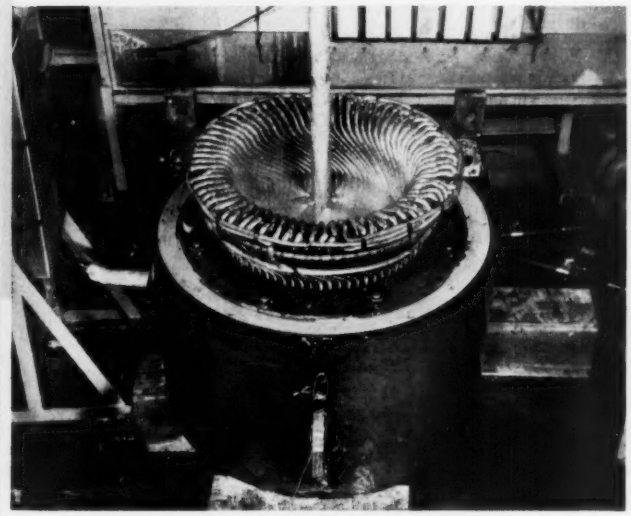


Fig. 3—Laboratory moisture-resistance test on the stator winding of a 950-hp, 4160-volt motor. The test lasted 275 hours, and 200 000 gallons of water passed over the winding.

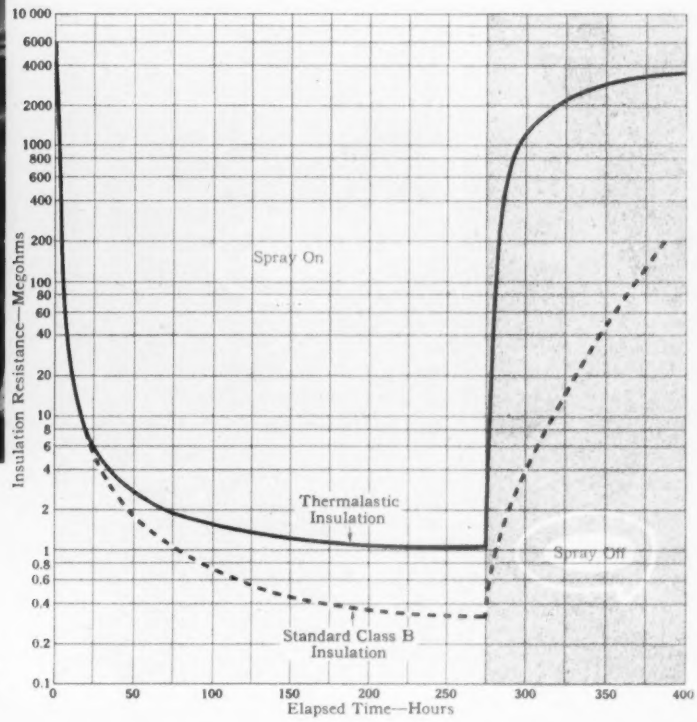


Fig. 4—These results of laboratory spray test show changes in insulation resistance of a Thermalastic-insulated winding compared to standard class B winding.

MERRITT HYDE

Personalities in Engineering

TO MERRITT HYDE a flying trip from East Pittsburgh to Tulsa, Dallas, Houston, Los Angeles, or Atlanta means about the same as a streetcar ride downtown for most people. Almost every week he makes one such trip, sometimes two. All this is occasioned because pipeline construction has been one of the most flourishing of businesses and because Hyde has become widely recognized as the outstanding authority on pipeline electrification. Very few pipelines in the United States have been electrified in the last 15 years in which he has not participated—usually in the very earliest planning stages. And many lines abroad.

Although the gigantic Trans-Arabian pipeline across the desert of Saudi Arabia, from the Persian Gulf to the Mediterranean, is powered by steam turbines and diesel engines, it makes extensive use of electrical controls. Much of the planning was done by Hyde, who had the additional satisfaction of helping supervise the initial operation.

Several of the major pipeline companies insist on having Hyde participate in the earliest stages of a pipeline's conception. Such a reputation is compounded of technical skill, engineering honesty, a cooperative spirit, and a warm personality. His word on all electrical aspects of pipelines is accepted almost without question by his associates at Westinghouse and by members of the pipeline industry alike.

Hyde received his collegiate training in his native state of Ohio. He graduated from Marietta College, majoring in physics. His liking for physics led to his decision to become an engineer. Physics must have liked him, too, for his grades were so good that they won him a fellowship to study electrical engineering at Case, where he obtained a bachelor degree in 1922, followed by an E.E. degree. Marietta must have liked Hyde, too, for in 1949 he was made a trustee, a responsibility he takes seriously; also, in 1948, he was awarded a Sc.D. from that school.

Hyde came directly to Westinghouse from engineering school, and, after the usual months in student training, moved with equal directness into the department in which he is now located, Industry Engineering. The first eight years he was occupied with General Mill activities, and in particular cement mills. He became an authority on the electrification of cement mills, and he was asked to prepare the section on cement mills for the Sixth Edition of the Standard Handbook. Also while in this group he had a great deal to do with the development of a high-torque synchronous motor and control for cement-mill use.

Then followed a four-year period working with construction-industry applications. Many famous buildings, such as the U.S. Supreme Court Building and the Archives Building, have electrical systems he helped to bring into being.

In 1935 began the category of work that has led him to specialize largely in pipelines. This was the general field of petroleum and chemical applications. This assignment led to engagement in the planning of major pipelines, a project made particularly necessary by the submarine activity of the early 1940's. The first was the 1260-mile Plantation Pipe Line from Baton Rouge, Louisiana, across the southeastern states. Hyde served as electrical consultant to this firm for two years.

Then came the Big Inch and the Little Big Inch. He served as a member of the group of pipeline engineers who established the system of control for the 20-inch products line, and he helped design the extensive electrical control system for its 29 pumping stations.

Hyde has made many contributions to pipelines and refineries. Probably most outstanding are the centralized station control, diagram-type control boards for pumping stations, and the development of automatic-sequence control by local pushbuttons or remotely over supervisory-control apparatus.

Hyde, too, is well known in the petroleum industry for his activity in the American Petroleum Institute. He is currently chairman of a subcommittee for the preparation of a chapter on Pump Station Machinery in the new API manual on oil-pipeline transportation practices.

It would seem pretty difficult for someone on the go as much as Hyde is to exercise a hobby. But he succeeds in making his travel serve his hobby—color photography. He has a library of some 6000 slides taken all over the United States, Canada, Mexico, Central America, Western Europe, and the Middle East. He can do a Burton Holmes on a moment's notice. And a good one—as polished as the job of spec writing for a new pipeline. He does everything that way. The article that appears over his signature in this issue is printed almost without benefit of the editor's "blue pencil." See what we mean!

Zirconium—from Rarity to Reactors

In the whole field of materials, few, if any, have made the transit from obscurity to volume production as rapidly as has zirconium. While all high-quantity uses are now geared to the atomic age, its properties may win for it a place in industry.

ONLY FIVE years ago all the ductile, metallic zirconium in the world could have been placed in a shoebox. When sold, it brought about $250 per pound. Mention of it in the handbooks was but the sketchiest, it being classed as one of the rare metals.

This situation has drastically changed. By the spring of 1951, Westinghouse was producing ultra-pure crystal-bar zirconium at its Atomic Power Division in quantities measured in tons per month. And the cost had come down to less than $30 per pound. The Foote Mineral Company was also then producing small quantities of crystal-bar zirconium. The Carborundum Metals Company, Inc., is setting up to produce for the Atomic Energy Commission sponge zirconium (from which ductile zirconium is made) at the rate of 150 000 pounds per year for five years. Other firms are expected to enter the metallic-zirconium field.

Considering the production rates these facts imply, and the vast amount of work that has been done in the last three or four years in learning its properties, as well as how to roll, forge, machine, and weld it, zirconium has graduated from the rare-metals class.

The skyrocket rise of zirconium from the obscurity of rare elements to a place of importance on the metallurgical scene has been a dramatic one. It is also highly significant—significant that we are entering a new age, the age of nuclear energy. Compressed into a few months was the accumulation of a mass of zirconium know-how that would normally take decades to acquire; the compelling reason was the necessity of finding satisfactory materials to clad the fissionable-fuel elements of the prototype submarine reactor and for the reactor under construction for the submarine, the *Nautilus* being built at Groton, Connecticut.* Zirconium is also becoming a useful material for certain jobs in industry. As yet these are all low-tonnage jobs, but this may not always be so after industry has had an opportunity to get acquainted with it and as the price declines further. Zirconium, in short, is one of a growing number of generally useful by-products of the nuclear-energy program.

While zirconium has long been classed as a rare metal, its occurrence as a mineral is not rare. It is found in several forms of which the one of principal importance is zircon or zirconium silicate. Pure zircon is a golden colored crystal, well known to early students of gems. Zircon occurs in sands in many places of the world. The largest present sources are seacoast sands of Australia, India, and Brazil, but the United States has ample quantities in Florida and Oregon, and in the vast placer sands of Idaho. Reserves of good zirconium-bearing ores in the United States have been estimated as being between 4 and 14 million tons.

Zirconium's problems center not around supply but on the production of refined zirconium, particularly the variety that is purified of high cross-section elements, required for some purposes. Thousands of pounds of zircon are produced monthly by several firms in Florida, usually along with other desirable minerals such as rutile and ilmenite, from which titanium is produced.

The second most common zirconium-bearing ore is baddeleyite, an impure zirconium dioxide. It is available from Brazil, but is not important industrially at present.

The first step in the production of ductile zirconium is to run zircon sand through a series of mechanical concentrators that raise the content of ZrO_2 mixed with the silicon dioxide to about 65 percent. Powdered graphite is added to this concentrate and the mixture is fed to a single-phase arc furnace. Under the heat of the arc the zirconium oxide becomes zirconium carbide (ZrC). The freed oxygen combines with excess carbon to form monoxide gas. The solids remaining after this reaction, carbides of zirconium and silicon (ZrC and SiC), are heated with an excess of chlorine to form zirconium tetrachloride, silicon tetrachloride, and free carbon. At the temperature of formation both the chlorides are gases, but that of silicon is the more volatile. Hence they can be separated by leading them through a condenser where the

These are long crystal bars of high purity zirconium, here being steam cleaned after their formation in a deposition tank.

Prepared by Charles A. Scarlott from information supplied by U.S. Bureau of Mines, the Atomic Energy Commission, the Titanium Alloy Manufacturing Division of the National Lead Company, and the Westinghouse Atomic Power Division.

*The development of zirconium as a structural material for nuclear power reactors will be described in more detail in a subsequent article.

zirconium tetrachloride is solidified, while the silicon tetrachloride passes on through.

Titanium and aluminum compounds, which may also be present as impurities in the zircon sand, form very volatile chlorides and are removed from the $Zr\ Cl_4$ in the same manner as the silicon.

Raw zirconium tetrachloride, containing impurities such as iron chloride and some zircon that has escaped processing, is purified by sublimation in a hydrogen-atmosphere furnace. This purified zirconium tetrachloride is then reduced with magnesium, at a temperature of 850 degrees C, leaving metallic zirconium in sponge form, and magnesium chloride, which is separated by distillation. The process of producing zirconium sponge by the reduction of zirconium tetrachloride with magnesium is the development of W. J. Kroll and his collaborators at the U.S. Bureau of Mines.

If the hafnium must be eliminated, as is the case if the zirconium is to be used in nuclear reactors (because of the high rate of neutron capture by hafnium), it is removed by a secret process before the sponge form is reached.

At the time Mark I was built, the sponge produced did not have the requisite corrosion resistance for reactor application and therefore had to be put through an additional refining step called the crystal-bar process. (Later developments now enable the use of sponge zirconium for reactor application.)

To produce crystal-bar zirconium, crushed sponge is fed into a vacuum furnace containing iodine and central seed wire of zirconium. The wire is heated by an electric current. The iodine acts as a vehicle, combining with the sponge zirconium to form a gas, zirconium tetraiodide. When the gas molecules strike the heated seed wire, the zirconium is freed, to grow crystal-fashion on the wire, and the iodine, as a gas, returns to pick up more zirconium. In this way impurities are left behind and a ductile mass of zirconium, called crystal bar, forms on the seed wire. As the crystal bar grows in diameter its resistance decreases and its heat-radiating surface increases, making it necessary to pass an ever-increasing current through it to maintain the necessary iodide-dissociation temperature (1300 degrees C). The larger current increases the heat, which must be dissipated, and the total amount that can be conveniently dissipated sets a practical limit to the size of bar that can be made in this fashion. The furnaces used in the Westinghouse plant produced bar up to $1\frac{1}{8}$ inches in diameter and 50 feet long, or about 117 pounds of metallic zirconium in each batch, with average run weighing 60 pounds. Conversion of crystal bar (and now the improved sponge) to ingot of size suitable for rolling or forging is a melting operation. This must be done in a vacuum arc furnace to exclude oxygen and nitrogen.

Zirconium metal has numerous interesting properties that industry can use to good advantage when costs become more reasonable. Zirconium ingot of commercial purity can be had now for about $20 per pound. Remember that only 50 months ago prices were 15 times as much and almost none was to be had; this suggests the great progress that has been made cost-wise, and promises that further reductions lie ahead.

Zirconium is one of a few metals that avidly absorbs gases. It has a great capacity to capture hydrogen, nitrogen, and oxygen. Zirconium can be easily freed of hydrogen by heating in a vacuum. Oxygen can be removed by heating the zirconium in the presence of calcium. Nitrogen, however, once absorbed is almost impossible to remove. And nitrogen greatly affects the metallurgical properties of zirconium, i.e., increases hardness and brittleness, and adversely affects its corrosion resistance.

The affinity of zirconium for gases is both an advantage and a disadvantage. It greatly increases the cost and difficulty of preparing metallic zirconium, as has been discussed

The zirconium crystal bar emerging from the deposition tank. The liquid shown is water, which serves as a precaution against fire.

Here an ingot of zirconium is being tested for hardness before being put into production. It is 99.9 percent pure zirconium.

However, it is put to good use in vacuum tubes as a "getter" of those gases that are slowly released from other tube parts during operation and that would destroy the tube vacuum. Zirconium has also been used as grids in electronic tubes and as electrodes in certain lamps. Impure zirconium is hard and brittle. It has little value as a structural material. In the commercially pure form the oxygen and nitrogen have been reduced to below 0.2 percent. The principal remaining impurity is hafnium, which is present in the same ratio in which it accompanies zirconium in the original ore, i.e., between one and two percent. Hafnium, being closely related to zirconium, has little effect on its metallurgical or chemical properties but has a large effect on the nuclear behavior.

Commercially pure zirconium metal resembles stainless steel in appearance. It is ductile and malleable. It can be rolled and shaped by essentially conventional techniques. It can be readily welded in an inert atmosphere, such as helium.

Finely powdered zirconium burns, even spontaneously, with an intense white light and the emission of considerable heat. Before the days of photoflash lamps, powdered zirconium enjoyed extensive use in flash photography. It has also been used to a small extent for flares. But that does not mean that zirconium is dangerous to handle. In massive form it is fully safe. It can be readily machined as safely as stainless steel, although care must be taken with accumulations of small chips. It can be safely forged and rolled at red heat.

The outstanding virtue of ductile zirconium is its corrosion resistance. The metal is not attacked by ordinary atmospheres, by hot fresh water, or by salt water at ambient temperatures. It is resistant to most acids, particularly hydrochloric at room temperature, and to alkalies. The resistance of zirconium to corrosion has made it a favorite of surgeons for use as pins, screws, and plates for bone repairs and for surgical instruments.

TABLE I—COMPARISON OF CORROSION PROPERTIES

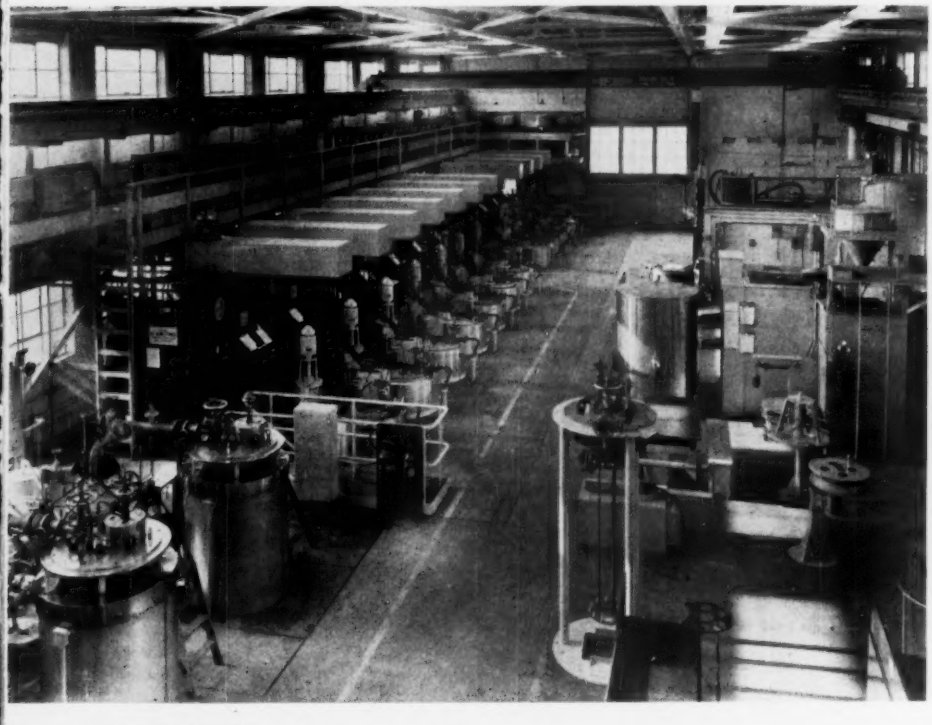
	Zirconium	Titanium	Tantalum	Stainless Steel (Type 316)
Acetic Acid	Excellent (5–99.5%; 60–100°C)	Excellent (5–10%; 20°C)	Excellent (All %; 20–392°C)	Good (5%–Glacial; 35–200°C)
Ferric Chloride	Poor (2.5–30%; 19–100°C)	Excellent (1–20%; 10–100°C)	Excellent (5–30%; 19°C–Boiling)	Poor 1–5%; 21°C–Boiling)
Hydrochloric Acid	Dilute—Excellent at all temperatures Concentrated at room temperature—Excellent Concentrated at boiling—Poor	Poor (5%–concentrated; 35–100°C)	Excellent (19%–concentrated; 19–100°C)	Poor (Dry, moist; 20°C)
Nitric Acid	Excellent (10%–concentrated; 19–100°C)	Good 5%–concentrated; 35–100°C)	Excellent (Concentrated; 19–86°C)	Dilute—excellent Poor in concentrated at boiling

Because of zirconium's corrosion-resistance properties certain industries are showing interest in it, particularly as a replacement for tantalum. Zirconium is more plentiful than tantalum, is lighter in weight, and, even now, it is cheaper. Its wear resistance, also, is better. In many ways its corrosion resistance is superior. It thus may have extensive use for tank linings, pipes, valves, immersion heaters, and the like. Its indifference to hydrochloric acid at normal temperatures makes it attractive for structural parts used in the production of magnesium, pulp paper, salt, and bleaches.

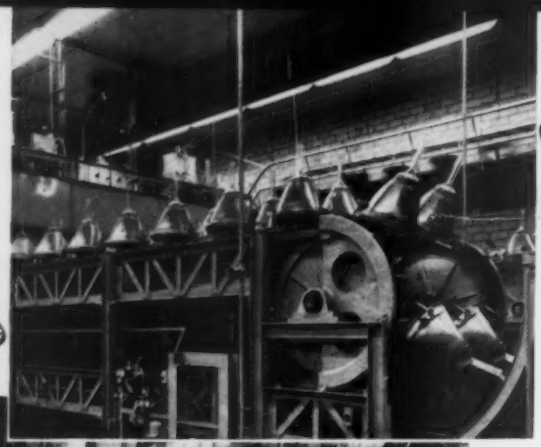
Zirconium is a useful alloying agent. The strength of copper is doubled through the addition of seven percent of zirconium. The hardened copper has good electrical conductivity (about 80 percent of copper) and is used for such purposes as resistance-welding electrodes. It also improves the high-temperature conductivity and tensile strength of cast copper-nickel alloys. Nickel containing up to ten percent of zirconium produces a hard alloy that requires no tempering and is useful in high-speed machine tools. In certain steels, small additions of zirconium improve hot-working properties, surface characteristics, and impact strength. Sometimes zirconium-nickel alloy is a substitute for tungsten in cutting tools. A small amount of zirconium added to magnesium alloys increases the corrosion resistance, because zirconium is a potent neutralizer for iron. Zirconium imparts high impact strength and good creep strength to pure magnesium.

Zirconium is a young material. Its ores are not in short supply. It presents no serious fabrication problems. Its cost will be reduced. While it is doubtful if it will ever be a competitor of the more common metals for large volume uses, it is certain to be extremely useful for a number of important, special purposes in many industries.

This is the production line for zirconium crystal bar. Here bars are grown in tanks by deposit of zirconium on hairpin-shaped wires of zirconium, as shown in the right foreground.



Filling with Solution



Draining Solution

Glass-to-Metal Seal

Baking

Coating Edges to be Joined with Glass Enamel

Television Picture

The period of adolescence of the television picture-tube industry has been a short one. In 1946, the first year of commercial television broadcast, about 100 000 tubes were produced—this has ballooned to an estimated eight million this year. Furthermore, in 1946, there were approximately ten manufacturers of television picture tubes. Today, there are at least 30 companies producing cathode-ray picture tubes.

The cathode-ray television tube is a precision device. Tolerances of as small as 0.0007 inch must be maintained for some spacings of the electron-gun assembly. Chemical purity of the fluorescent screen for some metal contaminants is held to one part in 25 million. Moreover, these stiff requirements must be met in large-scale production lines.

The production line consists of a series of semiautomatic machines, with endless conveyors carrying tubes from one operation to the next, at a rate of 16 feet per minute. A tube could theoretically be manufactured, tested, and packed in six hours. At present, the Westinghouse Electronic Tube Division is turning out over 1400 metal-cone picture tubes per day.

The inside of an electron tube must be immaculate. The slightest bit of dirt or rust would result in liberated gas after the tube is sealed, and cause low cathode emission—i.e., unsatisfactory light output. Every piece that goes into the tube must be treated to remove grease and prevent corrosion. Small parts such as the electrodes are heated to 1000 degrees C in an atmosphere of hydrogen. Hydrogen is used because it reduces the oxides and diffuses out of the metal readily during final tube exhaust.

Two types of metal have proved satisfactory for the metal cone, chrome iron and vitreous enameling iron. Both types are cleaned by degreasing and sandblasting. The iron cone is then dipped in an aqueous alkali-nitrate. This blackens the metal surface with a layer of iron oxide, which resists rust formation and oxide flaking during later operations.

Metal areas to be joined with glass are sprayed with a high-temperature enamel. This enamel coating accomplishes several things: first, it controls the thickness of iron oxide when the metal is heated; the enamel acts as a wetting agent for the glass during the glass-sealing operation; finally, the enamel provides an intermediate bond between metal and glass.

The initial steps are the sealing of the glass funnel neck and the face plate to the metal cone to form a bulb assembly. The glass and metal are quickly heated to approximately 1850 degrees F and the surfaces are slowly fused together. The enamel and glass fuse to the metal simultaneously. The desired strain pattern is set up in the bulb assembly by an intentional mismatch of the expansion characteristics of the glass and metal and by controlled heating and tempering following glass-sealing operations.

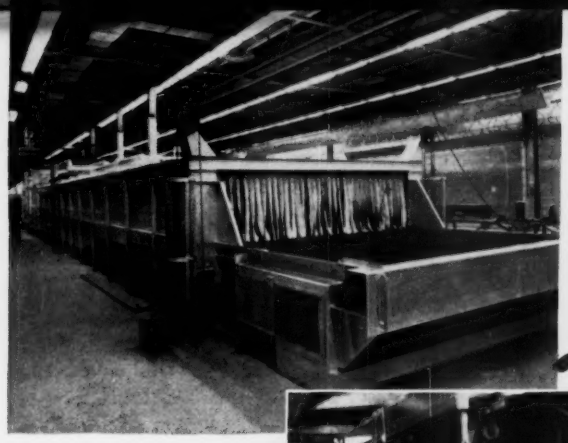
From this point on, the bulb assembly is hung on a conveyor belt, and progresses from point to point on the assembly line. The conveyor is a continuous belt from one assembly position to the next. If a tube should get past an operator the first time around, it circles and can be picked off when it reappears.

The bulb is thoroughly washed with caustic soda or ammonium bifluoride solutions to clean thoroughly the interior of the bulb. The bulb is placed in a face-down position and partially filled with an electrolyte solution, to which a phosphor material is added. The phosphor settles out of the solution to the face plate. After 30 minutes the tube is slowly tilted to remove the suspension liquids. This screen-coating operation is extremely sensitive to chemical contamination and mechanical vibration. Phosphors are adversely affected by as little as one part per several million of metallic contaminants. The temperature of the settling solution and the room must be accurately controlled, since proper distribution of the phosphor on the tube face depends on its being carried to the edges by convection currents. The final screen must be uniform in thickness and weight (4.3 to 6.0 milligrams per square centimeter) in order to give proper color and brightness. The bulb is air dried and the screen is inspected.

All of the bulb interior except the phosphor screen is painted with a graphite-silicate conductive coating that serves as a high-voltage anode and collector for secondary electrons emitted by the phosphor. This coating is dried (viewing face is turned up) with hot air.

The bulb is now placed in an indirectly gas-fired 100-foot lehr oven. As the bulb moves through the oven on a continuous belt, it is baked for 105 minutes, reaching a maximum temperature of about 400 degrees C. This removes water vapor and other volatile impurities from the bulb, screen, and internal coating. After baking, the bulb is inspected under ultraviolet light and any defective screens are returned to be washed and rescreened.

At the mount-sealing machine, the gun assembly is sealed into the neck of the tube. Manufacture of the gun is another process in itself. The major portion of handwork required in the manufacture of a cathode-ray tube goes into the gun. Filament, grid, screen grid, anode, and focusing electrodes are assembled in jigs and fixed in position with wire studs imbedded in Pyrex glass. This assembly is then welded to a glass stem containing supporting and connecting lead wires. The mount-sealing machine fuses the glass neck of the bulb assembly to the stem.



Parts Cleaning

Gun Making

Inspection

Tubes

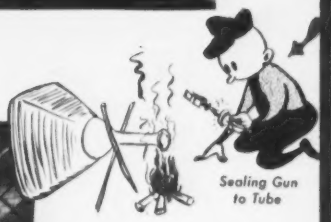
The stem tubulation allows air to be evacuated from the bulb. The tube is placed on an exhaust cart, which proceeds by steps through the straight-line exhaust machine. While being evacuated the bulb is gradually heated to about 400 degrees C. At the same time the metal gun parts are radio-frequency heated to remove absorbed gases in the metal.

The bulb is cooled slowly at a predetermined rate so that the most favorable mechanical stress conditions exist in the metal-glass bulb. At the final exhaust position, the tube is sealed off by melting the glass tubulation while the tube is still being evacuated. A base is cemented on the neck end of the bulb and the leads are soldered into the base pins.

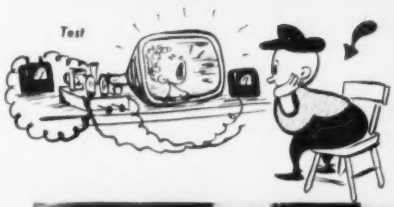
After sealing-off, the getter is heated, evaporating barium metal within the tube. Barium reacts with any gas molecules liberated during sealing-off and further improves the vacuum.

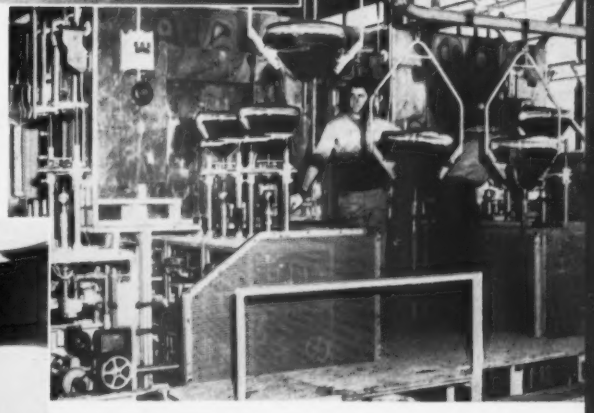
The completed tube is "seasoned" for one-half to three-quarters of an hour by applying voltages to the elements to stabilize the tube characteristics. Every tube is given a 100-percent electrical and mechanical test. These tests include brightness, brightness control, quality of focus, screen color, and uniformity of electrical characteristics such as gas pressure, cathode emission, and absence of electrical leakage across insulating members. Quality checks are performed on each day's production run. Also, a percentage of each week's production is taken at random from the production line and given an accelerated life test. This assures that manufacturing quality is maintained.

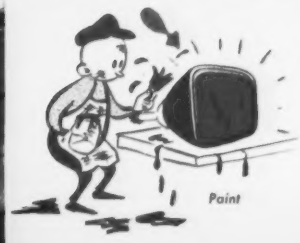
Finally, each tube is painted on the outside. The metal cone is given an insulating coating that prevents breakdown between the metal shell operating at high voltage and the deflection coil operating near ground potential.


Sealing Gun to Tube

Exhaust


Test



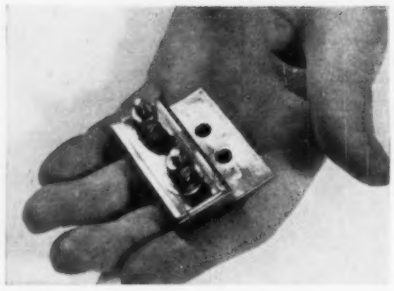

Paint

What's NEW . . . . . .

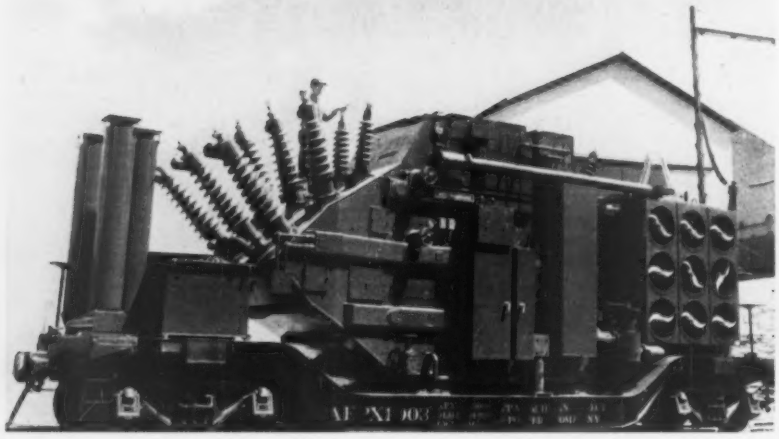
Compact Heater for Aircraft Instruments

Equipment in aircraft falls into one of two temperature categories. If an instrument is in a pressurized section of the plane, circulated heat keeps the part at the correct operating temperature. In an unpressurized compartment, such as the bomb bay, temperatures may become frigid at high altitudes and proper operation of the instrument ceases.

A small heater, 1½ inches wide, 2 inches long and a mere ½ inch thick—about the size of a penny match box—has now been developed, however, which keeps vital equipment in exposed areas functioning as it should. With a maximum weight of only eight ounces, the compact device permits concentrated heating of flat surfaces as small as 1 by 1⅜ inches. The metal parts are made from stainless steel and the insulation is zirconium oxide, a high-temperature compound. The resistance element has a rating of 100 watts. The heaters reach 1000 degrees F in 70-degree air.



Power Transformers on Wheels . . .



The bigger a power transformer, the bigger the problems of a spare unit. Frequently, a fourth single-phase transformer can be justified as a stand-by for a three-phase bank. In the case of some units, it is even feasible to haul a spare in by truck when a unit is removed from service.

Now comes still another answer—a mobile railway power transformer that can be moved around a utility system as conditions dictate. Most recent of these units built by Westinghouse is the 50 000-kva, 132-kv unit pictured. It is in service on the system of the American Gas and Electric Service Corporation. An 83 333-kva railway transformer was delivered earlier this year to the Bonneville Power Administration.

All equipment necessary for the operation of the transformer shown is mounted on the car. When it rolls onto the siding where it is to go into service, it is necessary only to mount arresters and make connections.

Four windings give several combinations of available voltages, and make it possible to use the transformer at a large number of substations. If desired, the transformer can be lifted off, and the car used for moving other large equipment.

Versatile New Locomotive . . .

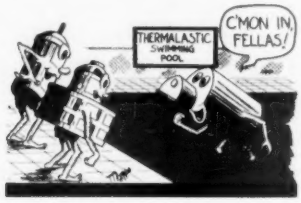
Diesel-electric locomotives with six individually powered axles have been built, and so have 2400-hp single-engine diesel locomotives, but the Fairbanks-Morse "Train Master," now in operation, is the first locomotive to have both these features.

Powered by a single 12-cylinder opposed-piston engine, the Train Master provides the necessary horsepower, transmission capacity, weight on drivers, and general design features to fit it not only for switching and heavy main-line freight hauls, but also for passenger service. The tractive force produced is 50 percent greater than in a 1600-hp, four-motor freight unit; thus it can pull one half more train on a given grade.

The Train Master is equipped with Westinghouse main generator and traction motors. In operation, the six motors are first connected across the main generator terminals in two parallel groups, three in a group. As locomotive speed increases, motor connections are automatically switched to result in three groups of motors in parallel, two motors to a group, and field strength is reduced by shunting. These connections are made by electro-pneumatic contactors energized by a motor-operated multiple switch.

Personality Profiles

Although generator designers and motor designers are often thought to be on different teams—one producing power and the other using it—a common goal such as insulation frequently solidly unites their forces. And so it was that the backfield of the team was formed to play the Thermalastic game. Calling signals were insulation quarterbacks *Graham Lee Moses* and *William Schneider*, both well trained for the post. Moses, who was graduated from Bliss Electrical School in 1923, heads up the insulation development group of the Generator Engineering Department, and Schneider, a 1936 graduate of Carnegie Institute of Technology, is his commercial, or application, counterpart. *E. C. Whitney* was graduated from the University of Michigan in 1935 and is manager of salient pole generator design. *M. R. Lory* is in charge of the design of large a-c motors. He got his B.S. from Colorado A. and M. College in 1927, and his M.S. from M.I.T. a year later. These "four horsemen" are one platoon of the field generals for the team that has brought Thermalastic from its early development days to its present place of importance in the insulation of waterwheel generators, synchronous condensers, and large alternating-current motors.



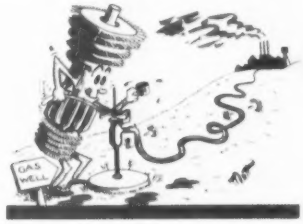
Dig a foundation, spread a few inches of cinders, a couple more of crushed rock, make an icing of concrete, lay the stone, and you have *M. H. Fisher's* recipe for a patio that will "last." And with that statement about one of his home-improvement projects, Fisher pretty well wraps up his philosophy of living: do it right.

Right must have been what he's done since his last appearance here in the March issue (this is his third time around), for in that time he has moved up a notch to manager of the General Mill Section, Industry Engineering. Where before he worried about one or two general industries, he now has the privilege of worrying about eleven men worrying about ten general industries ranging from material handling to pulp and paper products and machine tools.

As though his regular duties weren't enough to keep him busy, Fisher finds time to teach a course in fundamentals of industrial control at the Westinghouse Educational Center and to attend a management development course at the University of Pittsburgh.

Fisher's knowledge of regulating systems reads "experience." Hailing from Montgomery, Alabama, he joined the Westinghouse student-training program in 1941. Shortly afterwards, he moved to the Motor Division and six years of development and application of Rototrol rotating regulators. With his transfer to the industry engineering group in 1947, he began to acquire knowledge of the control needs of basic industries such as textile and paper. In 1952 he was appointed manager of his section.

T. J. Putz's engineering experience reads turbines, from the very time he came to Westinghouse. Upon graduation from the University of Illinois in 1938, Putz joined the Steam Division, where he spent several years in development engineering



helping to solve blade problems. Next he switched to control for central-station turbines; then to marine-turbine engineering. In 1944 he was given charge of the engineering section handling gas and steam-turbine locomotives. Since that time his section has been expanded to include the engineering of all gas turbines for land use, i.e., everything except aviation gas turbines.

In spite of the press of engineering and design work involved in a relatively new field, Putz finds time to assist with turbine applications. Early this year, for example, he made a flying trip to Venezuela to help a major oil company with the application of gas turbines for a central-station power plant. This is the fifth appearance for Putz on this page, representing five articles on various phases of turbine design and application.

New Literature

Choosing a Conversion System. Because electrolytic processes used in the production of chemicals, aluminum, magnesium, and some phases of steel production have varied requirements, the choice of a method of obtaining d-c power is not always a simple one. A new booklet evaluates the factors involved. Consideration of the three basic conversion systems—ignitron rectifiers, motor-generator sets, and rotary converters—is followed by charts to help the user select the best operating voltage. Booklet B-5466.

• • •

Combustion Gas Turbines for Mechanical Drives—for such applications as natural-gas transmission, and in the chemical, refinery, steel mill, and other process industries—are described in a new 24-page booklet. Load diagrams, dimensioned outline drawings, performance curves, and colored cut-away drawings give data on the 1800-hp, simple open-cycle type; the 5000-hp, compound open-cycle unit with regenerator; 5300-hp, compound open-cycle unit; and 7000-hp, simple open-cycle unit. Design and structural features are illustrated, and twelve factors in selection are listed. Booklet B-5859.

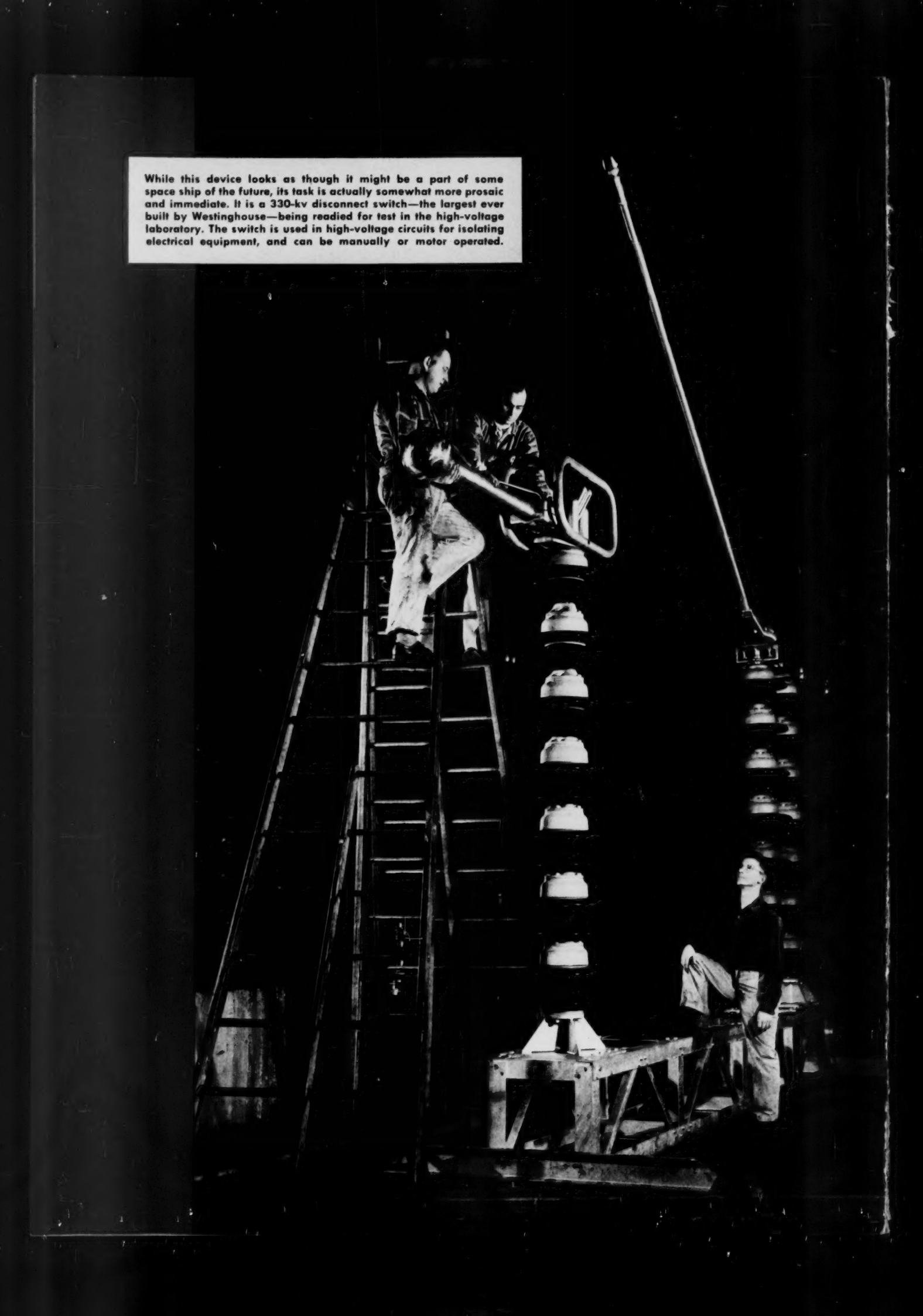
• • •

Electrical Equipment for the Automotive Industry is described in a new 36-page booklet. The characteristics of motors, controls, packaged drives, dynamometers, and other equipment as applied to automotive production lines are discussed. Also included is a handy reference to some 29 other booklets that describe individual equipment in more detail. B-5651

• • •

Specialty transformers fall into two groups, with different degrees of "specialness." One is the essentially standard variety, which includes general-purpose, machine-tool, signaling, control, low-power pulse, and aircraft power transformers. The other is the more special, and includes those that are tailor-made from basic components, or from specially designed components. Both types are discussed in a new 18-page booklet; included are complete details of transformer characteristics and construction for the standard line. Booklet B-5806.

To obtain literature, write to the Westinghouse Electric Corporation, P.O. Box 2099, Pittsburgh 30, Pa.



While this device looks as though it might be a part of some space ship of the future, its task is actually somewhat more prosaic and immediate. It is a 330-kv disconnect switch—the largest ever built by Westinghouse—being readied for test in the high-voltage laboratory. The switch is used in high-voltage circuits for isolating electrical equipment, and can be manually or motor operated.